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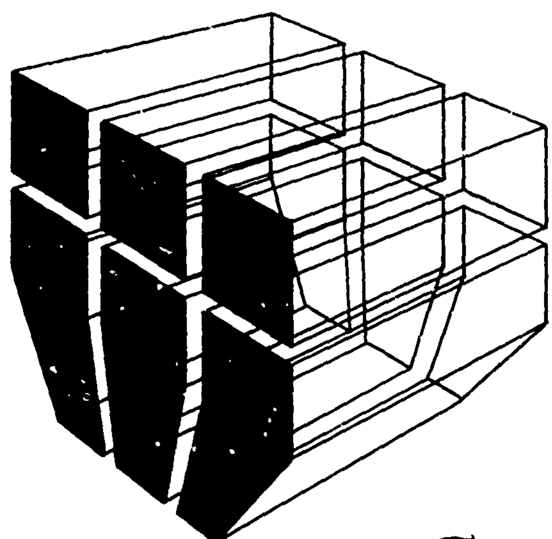
Corrosion Protection Selection Guide for
Rapid Deployment Joint Task Force Facilities

Corrosion Protection for Military Construction in the Middle East

AD-A162 258

by
V. Hock
V. Shea
R. Lampo
J. R. Myers



Preliminary information is given for corrosion mitigation techniques that can be applied to U.S. Army construction in the Middle East. The environment in these countries is unique—desert sands, high winds, and warm, salt-laden air from the surrounding sea—allowing even the most durable materials to corrode. The current Saudi Oriented Guide Specifications were utilized as a basis from which recommendations were made to extend facility lifetime through application of state-of-the-art corrosion mitigation techniques.

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Preliminary information is given for corrosion mitigation techniques that can be applied to U.S. Army construction in the Middle East. The environment in these countries is unique--desert sands, high winds, and warm, salt-laden air from the surrounding sea--allowing even the most durable materials to corrode. The current Saudi Oriented Guide Specifications were utilized as a basis from which recommendations were made to extend facility lifetime through application of state-of-the-art corrosion mitigation techniques.

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FOREWORD

This work was performed for the Directorate of Engineering and Construction, Office of the Chief of Engineers (OCE), under Project 4A162731AT41, "Military Facilities Engineering Technology"; Task Area A, "Facilities Planning and Design"; Work Unit 070, "Corrosion Protection Selection Guide for Rapid Deployment Joint Task Force Facilities." The OCE Technical Monitor was Leslie Horvath, DAEN-ECE-E.

This work was completed by the Engineering and Materials (EM) Division of the U.S. Army Construction Engineering Research Laboratory (USA-CERL). Dr. R. Quattrone is Chief, USA-CERL-EM. Dr. James R. Myers is with JRM Associates, Franklin, OH.

COL Paul J. Theuer is Commander and Director of USA-CERL, and Dr. L. R. Shaffer is Technical Director.

CONTENTS

CONTENTS (Cont'd)

CONTENTS (Cont'd)

CONTENTS (Cont'd)

CORROSION PROTECTION FOR MILITARY CONSTRUCTION IN THE MIDDLE EAST

1 INTRODUCTION

Background

U.S. Army Corps of Engineers (CE) Military Construction in the Middle East is a multimillion dollar multiyear program with the objective of constructing and upgrading facilities for contingency use. The Middle East environment where these facilities are being constructed (i.e., Saudi Arabia, Oman, and Egypt) is quite different from conditions typical in the United States. The desert sand, high winds, and warm, salt-laden air create an environment corrosive to even the most durable materials and coatings. The corrosivity of the environment, coupled with unique operation and maintenance problems, can cause costly premature corrosion failures. Ways to maximize facility lifetime by mitigating corrosion in this environment are needed.

The Middle East Division has developed construction guide specifications, called Saudi-Oriented Guide Specifications (SOGS), specifically for Middle East Projects. These SOGS were developed from the CE's Guide Specifications (CEGS) in order to be more applicable to the work that was being done in the Middle East. The SOGS are presently in use by the Middle East Division for construction in most areas of the Middle East. Appendix A gives a cross-reference between CEGS and SOGS. SOGS covering corrosion protection merit study to insure they incorporate the most recent methods available.

Objective

The objective of this Interim Report is to present information on corrosion protection for facilities being constructed in the Middle East. The ultimate objective of this work is to incorporate all available information into a selection guide for field use.

Approach

The data necessary to develop corrosion protection information for facilities being constructed in the Middle East were obtained from three sources. First, the lessons learned from the performance of materials and protective coatings specified for previous CE construction in the Middle East were reviewed. Second, the performance of materials exposed to similar environments, both in the laboratory and field, was documented. Third, state-of-the-art materials were surveyed to determine those optimal for corrosion-resistance in Middle East facilities construction. All available data and experience will be combined as a corrosion protection selection guide in a future U.S. Army Construction Engineering Research Laboratory (USA-CERL) Technical Report.

Scope

This report concentrates on materials and protective coatings for corrosion mitigation of facilities being constructed in a highly corrosive environment such as found

in the Middle East. Information provided can apply to construction in most similar environments.

Organization

Lessons learned, performance of materials both in the laboratory and field, and state-of-the-art material surveys are combined and presented under the SOGS sections as listed by the CE's Middle East Division. Applicable SOGS are cross-referenced by subject in the Index at the end of this report.

Mode of Technology Transfer

It is recommended that the information in this report be incorporated into the SOGS and referenced where current guidance is lacking, incomplete, or outdated. Where applicable, this information should also be incorporated into the corresponding CEGS.

2 ENVIRONMENTAL CONDITIONS

A number of environmental factors must be considered before selecting materials for military construction in the Middle East. These include: (1) soil resistivity, (2) temperature, (3) relative humidity and rainfall, and (4) wind.

In addition, the environmental conditions are dependent upon geographical location; specifically coastal versus inland. Coastal data was obtained from Masirah Island, Oman and Ras Banas, Egypt and inland data was obtained from Thumarit, Oman. The average conditions are summarized for each location.

Coastal

Soil Resistivity

The following table rates corrosivity on a soil resistivity range:

Soil Restivity Range (ohm-cm)	Corrosivity Rating
0- 2000	Severe
2000-10000	Moderate to severe
10000-30000	Mild
>30000	Not likely

Using the soil box test method, some wet soil resistivities were read as low as 40 ohm-cm. The average resistivity ranged from 30 to 1500 ohm-cm for Masirah Island and less than 1000 ohm-cm for Ras Banas. This severely corrosive environment is primarily a result of the high chloride and sulfate content in the soil.

Temperature

The yearly mean temperatures are 78.8°F for Masirah Island and 78.4°F for Ras Banas. During the summer months the temperatures are considerably more extreme with highs above 100°F for a 4-month period.

Relative Humidity and Rainfall

The relative humidity is typically high. Masirah Island has an annual mean relative humidity of about 70 percent and less than 1 in. annual rainfall. Ras Banas has an annual mean relative humidity of about 43 percent and 4.4 in. annual rainfall.

Winds

The average coastal wind velocity is relatively high. Masirah Island has an average wind velocity of 21.9 mph and Ras Banas has an average wind velocity of 16.1 mph. In addition, at some locations such as Masirah Island, gale winds between 25 and 60 mph may occur at least once a month.

Summary

In coastal areas the combination of elements forms a highly corrosive, severe desert environment.

Inland

Soil Resistivity

Wet box soil resistivities ranged from 60 to 220 ohm-cm, which is severely corrosive.

Temperature

The yearly mean temperature is approximately 80°F with annual mean maximum temperatures higher than 100°F during summer months.

Relative Humidity and Rainfall

The annual mean relative humidity is 77 percent. This extremely high relative humidity is due to the high humidity during the summer. The total annual rainfall is generally less than 1 in.

Winds

The mean monthly winds are of moderate intensity with a large number of days with blowing dust and sand.

Summary

These conditions are also severe and extreme. It is obvious that corrosion problems are of major concern in this harsh environment.

3 SITEWORK

SOGS Section No. 02315: Steel H-Piles

Material

Material selection for steel H-piles should be based upon various critera. A study of cost, strength, and corrosion resistance should be considered. Two American Society for Testing and Materials (ASTM), grades of steel are suggested, depending on the application. ASTM grade A 588 steel[1] (0.25-0.4 percent Cv) is suggested for uses where the pilings will only be exposed to atmospheric conditions, and ASTM grade A 690[2] is suggested where there will be exposure to a splash zone or a salt spray environment.

Corrosion Mitigation

Regardless of the steel used in fabrication, H-piles should be coated. Coatings (including surface preparation, coating application, and coating formulations) recommended for sheet piling in **SOGS Section No. 02411** of this report are equally applicable for H-piles. H-piles can be jacketed with concrete for corrosion mitigation in the splash zone.[3] The jackets should extend from at least 3 ft above the mean high-water (MHW) line to at least 3 ft below the mean low-water (MLW) line. For severe conditions or where significant wave action can be anticipated the jackets should completely cover the H-piles from at least 3 ft below the MWL to the underside of the deck or bent. (Wave action is a function of the average height of the waves as they break. Assuming that light wave action is approximated by 2-ft waves it is possible to define significant wave action as 4-ft wave height.) The concrete formulation and thickness requirements are described in **SOGS Section No. 02411** of this report. Alternatively, H-piles can be jacketed using an epoxy polyamide mastic (see **SOGS Section No. 02411** of this report).

Since all practical coatings contain holidays,* H-piles should have cathodic protection when in submerged and mud/soil zones.[4] Cathodic protection will also provide partial protection in the tidal zone (i.e., when the tide is in). Unless the structure is small or a large structure is extremely well coated, impressed current cathodic protection is usually more cost-effective than installing sacrificial zinc or aluminum-alloy anodes.

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[1]ASTM A 588-82, *Specification for High-Strength, Low-Alloy Structural Steel With 50 ksi (345 MPa) Minimum Yield Point to 4 in. Thick* (American Society for Testing and Materials [ASTM] Standards, 1983).

[2]ASTM A 690-81a, *Specification for High-Strength, Low-Alloy Steel H-Piles and Sheet Piling for Use in Marine Environments* (ASTM Standards, 1983).

[3]H. S. Preiser, "Jacketing and Coating," *Handbook of Corrosion Protection for Steel Pile Structures in Marine Environments* (American Iron and Steel Institute Washington, D.C., 1981), pp 53-66.

*Voids on the surface left uncoated by accident or caused by damage.

[4]A. W. Peabody and W. F. Cundaker, "Technical and Practical Approaches to the Design of Corrosion Control Methods," *Handbook of Corrosion Protection for Steel Pile Structures in Marine Environments* (American Iron and Steel Institute, Washington, D.C., 1981), pp 121-164.

For H-pile rehabilitation, coatings or barrier systems (e.g., surrounding a corroded H-pile section with 0.060-in.-thick rigid polyvinyl chloride [PVC] and filling the volume between the PVC and the H-pile with mastic) should be applied or installed.[5]

SOGS Section No. 02317: Cast-in-Place Concrete Piles

Casing Materials

ASTM A 252 steel casings[6] are considered acceptable for this application because their primary function is to provide a shell for forming cast-in-place concrete piles.

Corrosion Mitigation

When desired, exterior surfaces of the steel casings can be protected from corrosion in the atmospheric, tidal, splash, submerged, and mud/soil zones using the coatings, jackets, and cathodic protection described in **SOGS Section Nos. 02411 and 02315** of this report. For steel cylinders, however, metallic jackets are generally preferred because they are more cost-effective for splash-zone protection than those made of concrete.

Metallic jackets (leg wraps) can be attached to the casings easily using preformed Monel 400, copper alloy No. 70600, or copper alloy No. 71500 sheathing.[7] Since there are several ways to jacket steel casings, Figure 1 should be considered for specific applications. The two half-cylinders of sheathing are placed around the casings in the splash zone and welded together. The sheathing is, in turn, secured to the casing by welding. In general, it is advisable to seal the capillary between the metal jacket and the casing with a coal-tar mastic to mitigate galvanic corrosion. However, this procedure is not mandatory according to the results of field tests conducted by Creamer.[8] When noble-alloy jackets are applied to steel casings, it is desirable to apply a heavy-duty coating (e.g., coal-tar epoxy) to the steel extending at least 3 ft beyond the ends of the jackets.

SOGS Section No. 02411: Steel Sheet Piling

Material

Consideration should be given to using sheet piling fabricated from ASTM A690 steel in place of ASTM A 328 and A 572.[9] This suggestion is partly supported by the results of tests conducted at 10 different coastal and offshore locations which revealed

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[5] *Handbook of Corrosion Protection for Steel Piles Structures in Marine Environments* (American Iron and Steel Institute, Washington, D.C., 1981), pp 165-180.

[6] ASTM A 252-82, *Specification for Welded and Seamless Steel Pipe Piles* (ASTM Standards, 1983).

[7] H. S. Preiser.

[8] E. V. Creamer, "Splash Zone Protection of Marine Structures," Paper No. OTC-1274, presented at the Offshore Technology Conference, Houston, TX, 1970.

[9] ASTM A 328-81, *Specification for Steel Sheet Piling* (ASTM Standards, 1983); ASTM A 572-82, *Specification for High-Strength, Low-Alloy Columbium-Vanadium Steels of Structural Quality* (ASTM Standards, 1983).

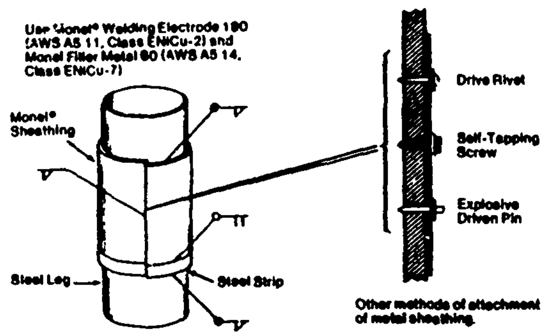

Figure 1. Field installation of Monel® Sheathing. (From Preiser, H. S., "Steel Selection," *Handbook of Corrosion Protection for Steel Pile Structures in Marine Environments* [American Iron and Steel Institute, 1981], p 57. Used with permission.)

that uncoated nickel-copper-phosphorus steel has at least twice the corrosion resistance corrosion resistance of uncoated carbon steel when exposed to the tidal, splash, and atmospheric zones.[10] Cost comparison is also an important consideration when selecting sheet piling materials.

Cathodic Protection

Sheet piling in contact with soil, mud, and saline waters should have cathodic protection using impressed-current systems with deep anode beds installed on the piling's shore side. The advantage of using deep anode beds is that both the water and soil sides of the piling can be protected by installing one system.

Since no cathodic protection method can protect the sheet piling in the splash, tidal, and atmospheric zones, two options are available for corrosion control in these areas: (1) concrete jackets and (2) protective coatings.[11]

Jacketing. When concrete jackets are used, they should extend at least 3 ft below the MLW line. The minimum cover over the steel should be 4 in. Durability of the jackets can be increased by using: cements with 8 weight percent or less tricalcium aluminate, aggregates that are not reactive with the cement, rich mixtures such as 1:1:3 or 1:1:2 for high-quality, maximum-density concrete, low water-to-cement ratios, air entrainment to obtain 10 to 12 percent air voids, and low-chloride content water and aggregate (combined chloride content is 50 to 100 ppm). Concrete jackets can also be used to rehabilitate deteriorated sheet piling. However, concrete jackets are not acceptable if they will be subjected routinely to impact by vessels or barges, since this would be expected to crack the concrete.

[10] S. K. Coburn, "Behavior of Steels in Marine Environments," *Handbook of Corrosion Protection for Steel Pile Structures in Marine Environments* (American Iron and Steel Institute, Washington, D.C., 1981), pp 196-197.
[11] H. S. Preiser.

An epoxy polyamide mastic is also useful for jacketing. This material can be applied to the atmospheric, splash, and underwater zones by troweling the two-component jacket in place. Divers wearing rubber gloves can apply this material underwater. Both atmospheric and underwater surfaces can be prepared by sandblasting techniques.[12]

Protective Coatings Other Than Jacketing. When jacketing is not considered cost-effective, protective coatings should be applied to the sheet piles (at least on the splash, tidal, and atmospheric zones). Available protective coatings that have been used successfully in this application are: (1) coal-tar epoxy SSPC Paint No. 16 (or CE Specification No. C-200); (2) epoxy polyamide MIL-P-24441* available in colors; (3) metallized zinc with vinyl, epoxy, saran, or furan seal and/or topcoats; (4) metallized aluminum with vinyl, epoxy, saran, or furan seal and/or topcoats; and (5) phenolioc mastics.[13]

A coal-tar epoxy method that gives excellent performance in marine environments is to prime with an epoxy, zinc-rich primer (CE No. E-303) to approximately 3.0 mils dry-film thickness (DFT), and then topcoat with two coats of coal-tar epoxy (CE No. C-200) to approximately 16 mils DFT total. For best results, this system should be applied to steel that has been prepared to at least a near-white metal finish (i.e., Steel Structures Painting Council [SSPC]-SP 10);[14] these coatings will cure considerably in 24 hr at 70°F and are almost completely cured in 24 hr at 140 °F.

Regardless of the coating system used, the surface preparation and coating application should be done indoors before shipping the sheet piling to the construction site.

Rehabilitation of Corroded Sheet Metal

Rehabilitation of corroded, in-service sheet piling should include the application of special polyamide-cured epoxies that will cure where moisture is present or underwater.[15] In general, the special epoxies require a sandblasted surface finish. These epoxies can also be used to repair damaged coal-tar epoxy.

SOGS Section No. 02455: Aircraft Tie-Down Anchors

Silicon red brass (i.e., copper alloys No. C69400, No. C69430, No. C69440, and/or No. C69450) aircraft tie-down anchors installed within 3 mi of any seacoast should have cathodic protection using properly sized sacrificial zinc anodes if the anchors will be exposed to soils aggressive to copper-based alloys. Similar cathodic protection should be applied to the copper-covered steel anchors used at locations greater than 3 mi from

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[12] R. W. Drisko, J. W. Cobb, and R. L. Alumbaugh, *Underwater Curing Epoxy Coatings*, Technical Report R300 (U.S. Naval Civil Engineering Laboratory [NCEL], May 1964).

*U.S. Department of Defense Military Standards.

[13] H. S. Prieser.

[14] SSPC-SP 10, "Near White Blast Cleaning," *Steel Structures Painting Manual Volume 2—Systems and Specifications*, 2nd ed. (Steel Structures Painting Council [SSPC], 1982).

[15] R. W. Drisko, J. W. Cobb, and R. L. Alumbaugh; R. W. Drisko and C. V. Brouillette, "Protective Coatings in Shallow and Deep Ocean Environments," paper presented at Western Region Conference, National Association of Corrosion Engineer (NACE), Honolulu, HI. November 1965.

the coast when the soils are aggressive to copper. Although many soils in the Mideast are not corrosive to copper and copper based alloy, conditions do exist, especially along the coast, where these relatively noble materials are adversely affected by the soil. The design life for the zinc anodes should be at least 20 years. In general, copper and copper-based alloys can be cathodically protected in most soils using less than 5 mA of current for each square foot of exposed metal.[16]

Soils known to be aggressive to copper and many of its alloys include those which are damp and have: (1) high sulfates and/or chlorides; (2) very low resistivities (less than about 500 ohm-cm); (3) high organic contents (particularly organic acids); (4) cinders; (5) poor aeration and support for anaerobic bacterial activity; (6) ammonia or ammonia-containing compounds; (7) inorganic acids; and/or (8) small quantities of sulfide.[17]

SOGS Section No. 02611: Concrete Pavement for Airfields

Portland Cement Concrete Airfield and Shoreline Paving

When seawater is used to wash the aggregate and as mix water, construction must be monitored very carefully. Without proper care, the potential exists for significant corrosion of uncoated reinforcing steel. Seawater can be used as mix water in the paving specification if epoxy-coated rebars are used and the concrete's total chloride content does not exceed 1.2 lb chloride/cu yd concrete. In the specification for concrete in building construction, the mix water is required to be fresh; in the reinforced-masonry specification, clear water is required. In addition, the paving concrete specification permits the use of seawater to wash the aggregate; however, the specification for concrete in building construction does not make this area clear. Each concrete specification is reasonable for its application, but since the two specifications are different, great care must be taken during construction to ensure that only fresh mix water is used in the concrete for building construction; similarly, aggregate for building construction should not be washed with seawater. A chloride meter[18] can be used to check the chloride concentration in the concrete mix to ensure it does not exceed 1.2 lb of chloride/cu yd concrete.

Coating Breaks

Damage during shipment and/or installation of epoxy coated reinforced steel (rebars) need not be repaired when the damaged area is less than 1/4 sq in. and the sum of all damaged areas in each 1-ft length of bar does not exceed 2 percent of the bar's surface area. All damaged areas larger than 1/4 sq in. shall be repaired in accordance with the applicable specification, and all bars with total damage greater than 2 percent of bar surface area shall be rejected and removed. The total bar surface area covered by a patch shall not exceed 5 percent.

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[16] O. W. Zastrow, "Galvanic Behavior of Underground Cable Neutral Wires and Jacketing Materials," *Materials Performance*, Vol 16, No. 11 (November 1977), pp 18-21.

[17] J. R. Myers and A. Cohen, "Underground Behavior of Copper Water Tube," paper presented at the Annual Meeting of the American Water Works Association (AWWA), Miami, FL, May 1982.

[18] P. A. Howdyshell, *Corps of Engineers Concrete Quality Monitor: Operations Guide*, Technical Report M-293/ADA102753 (U.S. Army Construction Engineering Research Laboratory [USA-CERL], May 1981).

SOGS Section No. 02618: Pavement Markings (Airfields and Roads)

Materials

TT-P-1952,* an acrylic water emulsion marking paint, should be used on asphalt pavements since it is more flexible than TT-P-85 and, therefore, less likely to crack the asphalt substrate. This is particularly true with slurried-sealed pavements. Either TT-P-1952 or TT-P-85 can be used on other pavements (e.g., concrete). When reflective paint is specified, spherical glass beads conforming to TT-P-1325 Type III, Gradation A, should be used. With TT-P-85, granules conforming to TT-G-490 Type I may be used instead of beads. Paint must be stored properly and used within 1 year of purchase. Beads must be kept dry; those sticking together should be discarded rather than being reclaimed.[19]

Surface Preparation

New pavement surfaces shall be allowed to cure no less than 30 days before applying masking materials.[20] Before painting over existing markings, all loose paint must be removed by waterblasting or mechanical methods. Concurrently, all chalk should be removed from the existing paint, especially when TT-P-1952 is to be applied as the overlay. The total paint accumulation for a marking system should never exceed four coats before it is removed completely.

Application

Paints should not be thinned before application, especially when beads are to be applied, because thinning could adversely affect the beads' embedment depth. Both TT-P-85 and TT-P-1952 should be applied at a rate of 100 to 110 sq ft/gal. This application corresponds to wet and dry film thicknesses of about 0.015 and 0.007 to 0.008 in., respectively. The TT-P-1325 beads for TT-P-85 and TT-P-1952 paints should be applied at 10 lb/gal paint; TT-G-490 granules for TT-P-85 should be applied at 1.7 lb/gal paint.

Paint should not be applied during high winds, high humidities, low temperatures (less than 40°F for TT-P-85 and less than 50°F for TT-P-1952), or unusually high temperatures (e.g., when the pavement temperature exceeds about 95°F). Paint temperatures shall be maintained within these same limits.

SOGS Section No. 02711: Fence, Chain Link

Corrosion Control

Only PVC-clad galvanized-steel chain-link fencing should be used for permanent installations in aggressive coastal atmospheres. Galvanized steel and vinyl-clad steel without the zinc coating cannot be expected to provide the desired life expectancy in

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*Federal specifications.

[19] R. W. Drisko, *Tech Data Sheet No. 79-05* (NCEL, Naval Construction Battalion Center, Port Hueneme, CA, April 1979).

[20] Corps of Engineers Guide Specification (CEGS)-02577, *Pavement Markings (Airfields and Roads)* (U.S. Army Corps of Engineers [CE], Office of the Chief of Engineers [OCE], January 1983).

these environments.[21] In addition, the posts, gates, and accessories for chain-link fences must have a galvanized coating under the PVC cladding.[22] The posts, gates, and accessories should have a coating system that consists of: (1) zinc galvanizing of 1.0 ± 0.1 oz zinc/sq ft and (2) PVC coating thermally fused and bonded to a primer, which is thermally cured onto the zinc galvanizing. The cured PVC coating system shall be a minimum of 0.007 in. thick. The vinyl topcoat should approach 0.015 in. for severe atmospheric conditions, where the climate is warm and humid and the air is salt-laden. The 2 oz/sq ft of galvanizing on the fence fabric should have a 0.020-in.-thick vinyl topcoat for severe atmospheres; a 0.007-in.-thick topcoat is considered acceptable for locations more than about 1500 ft away from a saltwater body. For the desert, a vinyl topcoat of light brown or tan would be more suitable than dark green.

Components of the gate reinforcement systems currently installed to prevent forced entry into secure areas (e.g., by ramming the gates with vehicles) also require corrosion control.[23] The wire rope, chain, clamps, and accessories require a vinyl coating. Vinyl coating the wire rope and chain is especially important since it will contact vinyl-coated components of the security fence or gates. Uncoated wire rope and chain rubbing against these coated components would abrade the vinyl coating from the basic security system.

For inland locations with dry, noncorrosive atmospheres, the following specifications can be used for the fence hardware:

1. Zinc galvanizing of 1.0 ± 0.1 oz zinc/sq ft.

2. Chromate conversion coating of 30 ± 15 mg/sq in.

3. Clear crosslinked acrylic polyurethane coating. The thickness of the clear coating shall be approximately 0.0005 ± 0.002 in.

(Note: the above system is for nonvinyl-coated items. The chromate conversion and clear polyurethane coatings should not be specified for vinyl coated items because they may interfere with the vinyl's bonding.)

Grounding

When security fences must be grounded, solid copper rods and straps should be used. The ground rod-to-soil potential should be surveyed annually to determine where, if any, active corrosion of underground copper is occurring. This survey should be in addition to the routine ground-resistance measurements to ensure proper grounding of

[21] E. S. Matsui, *Protection of Fencing Materials in a Marine-Atmosphere Environment*, Techdata Sheet No. 72-02 (NCEL, Port Hueneme, CA, September 1972).
[22] E. S. Matsui, *PVC-Coated Posts and Accessories for Chain-Link Fences*, Techdata Sheet No. 76-16 (NCEL, Port Hueneme, CA, September 1976).
[23] K. Gray, *Reinforcement System for Chain-Link Gates*, Techdata Sheet 78-40 (NCEL, Port Hueneme, CA, July 1978).

the security fences. The correlations between copper tube-to-soil potential and the underground corrosion activity of copper for most soils are:[24]

Potential, volt vs $Cu - CuSO_4$ half cell	Corrosion Activity
-0.5 or more negative	Copper is well protected; suggests that the copper is cathodically protected
-0.25 or more negative	No corrosion in most soils
-0.1 or less negative	May be corroding
0.0 or positive	Probably corroding

SOGS Section No. 02712: Fence, Barbed Wire

When permanent barbed-wire fences are to be installed, the posts (i.e., the line, end, corner, and intermediate posts), bracing members, and stay wires should be galvanized and vinyl-coated in accordance with the guidelines under **SOGS Section No. 02711** for chain-link fence. Concrete placed around the posts should be nonaggressive to steel and mixed in accordance with **SOGS Section No. 03316.** Driven posts should be galvanized and vinyl-coated to mitigate atmospheric corrosion.

The barbed wire for coastal or heavy industrial environments should consist of vinyl-coated galvanized wire with aluminum-alloy barbs. The barbs must not be made of 7000 or 2000 series aluminum alloys because they may undergo intergranular corrosion and/or stress cracking. Alternatively, stainless-steel saw-tooth tape can be used. The surfaces of stainless steels used for this application typically develop a tannish-yellow tarnish film in coastal atmospheres; the color of this film is considered to be compatible with the tan or light-brown color that should be used fc the vinyl topcoat on posts and accessories.

Grounding

When permanent or semipermanent barbed-wire fences must be electrically grounded, solid copper rods should be used.

Saw-Tooth Tape

When stainless-steel saw-tooth tape is used for concertina-type fencing, the design pattern for the tape should not induce premature corrosion-fatigue fracture in coastal atmospheres. There should be no sharp notches at points where the tape will be flexed (i.e., subjected to fatigue stresses) during high winds or sandstorms.

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[24] *Manual on Underground Corrosion in Rural Electric Systems* Bulletin 161-23 (U.S. Department of Agriculture [USDA], Rural Electrification Administration, October 1977).

Hollow Fencepost Corrosion Prevention

When hollow cylinder-type fence posts are used for permanent barbed-wire fences, they should either be capped or filled with a well-mixed, fine aggregate, nonaggressive concrete.

4 CONCRETE AND METALS

SOGS Section No. 03316: Concrete for Building Construction

Corrosion Mitigation of Reinforcement Steel (Rebars)

Unacceptable corrosion of rebars can be expected when the concrete contains moisture, oxygen, and more than about 1.2 lb chloride (as Cl^{-1})/cu yd concrete. Concrete must be mixed using freshwater, freshwater-washed aggregate, and cement that contain no more than 50 to 100 ppm chloride (as Cl^{-}). Calcium chloride and other halide-containing hardening accelerators should not be added to the concrete mix.[25]

Concrete With Rebar

Corrosion of rebars can be mitigated effectively by an adequate cover of high-quality, properly placed, consolidated and cured, low-permeability concrete. In general, rebars should be covered with 3.0 in. of sound (free of voids and cracks) concrete for severe environments. The current edition of American Concrete Institute (ACI) Standard No. 318 reportedly provides the minimum high-quality concrete cover required for the various diameter rebars used in buildings.[26]

The water-to-cement ratio of the concrete mix should be low (about 0.4 to 0.5) to provide the alkalinity and impermeability required for effective rebar corrosion control. Extended moist curing at favorable temperatures further insures that the concrete will isolate the rebars well enough from aggressive, chloride-containing environments.[27]

Concrete mixes also can be formulated with a corrosion inhibitor to mitigate rebar corrosion. Typically, 2 to 4 percent calcium nitrite (based upon cement weight) will effectively mitigate the corrosion of steel exposed to aggressive concrete.[28]

Rebar Coating

Fusion-bonded epoxy-coated rebars (ASTM D 3963-81)[29] are considered the best available solution to the rebar corrosion problem.

Rehabilitation of Corroded Rebar

If there is rebar corrosion (e.g., as indicated by cracking or spalling and/or rust stains on the concrete) in buildings scheduled for rehabilitation, the weakened concrete should be removed. After removing all rust from the rebar surfaces mechanically, a zinc-rich organic coating should be applied to the exposed rebars before replacing the

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[25] C. Hahin, "Corrosion-Resistant Design Guidelines for Portland Cement Concrete," paper presented at Corrosion/83, Anaheim, CA, April 1983.

[26] C. Hahin.

[27] D. Whiting, "Concrete Materials, Mix Design, Construction Practices, and Their Effects on the Corrosion of Reinforcing Steel," paper presented at Corrosion/78, Houston, TX, March 1978.

[28] J. T. Lundquist, Jr., A. M. Rosenberg, and J. M. Gaidis, "Calcium Nitrite as an Inhibitor of Rebar Corrosion in Chloride-Containing Concrete," *Materials Performance*, Vol 18, No. 3 (March 1979), pp 36-40.

[29] ASTM D 3963-81, *Epoxy-Coated Reinforcing Steel* (ASTM Standards, 1983).

concrete. A breathable coating (e.g., polyvinyl acetate latex) should then be applied to the concrete building's exterior surfaces. Concurrently, an impermeable coating should be applied to interior surfaces of the structure's outside walls.

Aggressive Soils

Subsoils can be aggressive to conventional concrete if their sulfide (as S^{-2}) content exceeds about 100 mg/kg air-dried soil.[30] Similarly, soils with sulfate concentrations greater than about 3000 mg/kg air-dried soil readily attack conventional concrete. Cements with high sulfate resistance should be used when these sulfide and sulfate limits are exceeded. Type V, Portland cement is recommended (ASTM C150) for use when high sulfate resistance is desired. This would be required for water soluble sulfate in soil of 0.20 to 2.0 percent by weight. If the percent by weight of water soluble sulfate content is greater than 2.0 Type V plus Pozzolan cement should be used.[31] Concrete also can be isolated from aggressive soils by applying properly formulated bitumastic-type coatings (e.g., Mil-C-18480) to the soil-side surfaces. The bitumastic-type coating should be at least 2 mils thick.[32]

SOGS Section Nos. 05020 and 05021:* Ultrasonic Inspection of Weldments and Ultrasonic Inspection of Plates

Ultrasonic inspection is an effective method for evaluating corrosion damage (e.g., stress-corrosion cracking[33]) and locating internal flaws and hidden crevices in welds.[34] However, limitations of this testing technique must be recognized, including:[35] (1) manual operation requires careful attention by experienced technicians; (2) extensive technical knowledge is required for developing inspection procedures; (3) components that are rough, irregular in shape, very small or thin, or not homogeneous are difficult to inspect; (4) discontinuities in a shallow layer immediately under the surface may not be detected; (5) couplants are needed to provide effective transfer of ultrasonic wave energy between the transducers and the parts being inspected; and (6) reference standards are needed both for calibrating the equipment and characterizing flaws and defects.

The need for reference standards is especially important with regard to evaluating corrosion damage. Unless the tester knows what he/she is looking for and has a reference standard for that flaw or defect, the problem may go totally undetected by even a skilled operator.

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[30] D. Knofel, *Corrosion of Building Materials* (Van Nostrand Reinhold, New York, 1978), pp 17-22.

[31] *Building Code Requirements for Reinforced Concrete*, ACI 318-83 (American Concrete Institute, Detroit, MI, November 1983), pp 16.

[32] D. Knofel.

*These SOGS have been combined because the comments provided apply to both.

[33] "Ultrasonic Inspection," *Metals Handbook*, Vol 11 (American Society for Metals, Metals Park, OH, 1976), pp 161-198.

[34] "Nondestructive Inspection," *Metals Handbook*, Vol 11 (American Society for Metals, Metals Park, OH, 1976), pp 340-355.

[35] "Ultrasonic Inspection."

SOGS Section No. 05120: Structural Steel

Under no circumstances should naturally weathering steels (e.g., high-strength, low-alloy steels such as ASTM A 588) be considered for applications that will be exposed to chloride-containing, highly humid, or wet environments.[36] If these structures already exist and have corroded, they can be protected from further deterioration only by treatment with properly selected and applied coatings. Coating corroded weathering steels can be very expensive, often requiring up to three times the amount of sanding and coating needed for regular grades of structural steel.[37] Furthermore, special coating systems (e.g., epoxy polyamide primer and polyurethane topcoats) may be required to insure long-term protection for weathering steels exposed to aggressive environments.

Regardless of the steel used, designs for structures that will be exposed directly to weather (e.g., at desalination plants) should not include sections that will collect water.[38] As an alternative, drain holes could be included in the design. Flange-to-flange (angle-to-angle and flap-to-flap) crevices should be sealed by welding or by applying nonhardening sealants. Equally important, designers must allow for easy access to the structural steel so that it can be cleaned and coated properly once the structure is completed.

When structural steel has direct exposure to coastal environments, consideration should be given to metal-spraying the steel components with aluminum (either before or after assembly). If the components are sprayed before construction, aluminized bolts and nuts should be used to assemble the steel framework. For severe coastal or industrial environments, it may be necessary to apply an organic coating system to the metallic aluminum.

All galvanized steel that will have direct exposure to salt-laden coastal atmospheres should be coated as part of the construction project.

All sharp edges on structural steel should be rounded before coating. Otherwise, a coating thinner than desired will result on the edges and lead to premature coating failure at these spots.

SOGS Section No. 05141: Welding, Structural

When aggressive environments require that structural steel be coated with a high-performance product, all sharp protrusions resulting from welding should be smoothed first. Equally important, all weld spatter should be removed to achieve an effective coating system.

[36] B. Paul, "Weathering Steel Prompts Big Debate," *American Painting Contractor*, Vol 60, No. 3 (March 1983), pp 35-36; "An Evaluation of Weathering Steel Bridges," *Rural and Urban Roads*, Vol 21, No. 5 (May 1983), pp 32-33.

[37] "Bridge Painting Cost Overrun Highlights Weathering Steel Woes," *The AHDGA Market News* (American Hot Dip Galvanizers Association [AHDGA], Washington, D.C., Winter/1983), pp 6-7.

[38] K. Treadway, "Corrosion of Steel in Buildings," *Bulletin of the Institution of Corrosion Sciences and Technology*, Vol 19, No. 4 (July 1981), pp 4-5.

SOGS Section No. 05210: Steel Joists

For open-building construction and highly humid sites, open-web steel joists should be designed such that they will not collect water, dust or salt. Equally important is that the joist design does not contain crevices. The surfaces of all steel joists will be suitably prepared and field coated after construction and while still easily accessible. When they are expected to be exposed to a coastal desert environment, the joists should be made of aluminized steel. In addition, consideration should be given to using galvanized-steel joists for enclosed buildings in highly aggressive atmospheres.

SOGS Section No. 05301: Roof Decking, Steel

The roof decking should be made of galvanized steel. When the decking will be "nested" for shipment or storage, the manufacturer should chromate-treat and lightly oil galvanized-steel surfaces to prevent "white-rust" formation (i.e., localized or spotty corrosion of the zinc coating).

The nested decking should be enclosed with a heavy-duty, waterproof wrapping protected on the ends by steel shrouds for long-distance shipments.

SOGS Section No. 05500: Miscellaneous Metal

For highly humid, salt-laden, or industrially polluted atmospheres, outdoor use of bare galvanized steel should be discouraged. Depending on the structure or component, either organically coated aluminized-steel or an anodized aluminum should be chosen. If galvanized steel is selected, it must be appropriately field- or factory-coated.

Wire-Rope: Antenna Guys and Associated Hardware

For coastal environments, wire-rope antenna guys and associated hardware should be made of aluminized steel. Consideration should be given to using a factory-applied organic coating (e.g., a UV resistant vinyl)[39] to supplement the protection afforded by the aluminum on the wire rope. Type 304 stainless steel is an effective material for wire-ropes at most coastal locations. However, Type 304 (or even Type 316) stainless-steel rope must not be used where it might be exposed to either quiescent seawater or chloride-containing soils.[40] If galvanized-steel wire and accessories are used, they must be vinyl-coated at the factory.

Ladders and Accessories

When the anticipated loads and fire codes permit, ladders and accessories should be made of an aluminum alloy. Fire escapes and accessories should be made of aluminized steel which is organically coated after erection. A properly formulated vinyl system usually is good enough for the latter application at most coastal sites. Fiberglass-reinforced plastic (FRP) ladders should be used when possible. FRP ladders must be

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[39] J. R. Myers, *Preliminary Corrosion-Control Survey of King Faisal and King Abdulaziz Naval Bases, Saudi Arabia*, report prepared for HBH Company (Arlington, VA, October 1980).

[40] V. C. Peterson and D. Tamor, "Tests Show How Seawater Affects Wire-Strand and Rope," *Materials Protection*, Vol 7, No. 5 (May 1960), pp 32-34.

factory coated with a material that can withstand the ultraviolet exposure and the abrasion caused by personnel foot traffic.

Guard- and Handrails

Guard- and handrails should be made of a suitable aluminum alloy such as 6061-T6.

Floor Gratings

For indoor use, FRP floor gratings should be considered. Elsewhere, aluminized (aluminum coated) steel, aluminum alloy, or brass gratings should be used.

Aluminum

Aluminum and its alloys should not be used in aqueous environments with a pH of less than 6.5 or greater than 8.5. Similar restrictions apply to lead, lead alloys, zinc, and zinc alloys.

Copper

It is also important that copper not be used where soft water (such as rain) flowing over the surface (such as roof flashings) will subsequently come into contact with either an aluminum alloy or aluminized steel. The transport of copper ions to the aluminum surface would cause unacceptable pitting on the latter material.

SOGS Section No. 07112: Bituminous and Elastomeric Waterproofing

Definition

A bituminous membrane is a waterproof barrier that protects against the penetration of water under hydrostatic pressure or water vapor. To resist hydrostatic pressure, the membrane should be made continuous throughout the walls and floor of a basement. It should also be protected from damage during building operations and should be installed only by experienced workers under competent supervision. It usually consists of three or more alternating layers of hot, mopped-on asphalt or coal-tar pitch and plies of bituminous-saturated felt or woven cotton fabric. The number of moppings exceeds the number of plies by one. An alternative is a 1/16- to 1/8-in.-thick layer of butyl rubber secured with a compatible adhesive.[41]

Material Types

Bituminous-saturated cotton fabric is stronger and more extensible than bituminous-saturated felt, but also is more expensive and more difficult to install. At least one or two of the plies in the membrane should be of saturated cotton fabric to provide strength, ductility, and extensibility to the membrane. When vibration, temperature changes, and other conditions conducive to displacement and volume changes in the basement are expected, the relative number of fabric plies may be increased.

The minimum weight of bituminous-saturated felt used in a membrane should be 13 lb/100 sq ft. The minimum weight of bituminous-saturated woven cotton fabric should be 10 oz/sq yd.

Application

Although a membrane is held in place rigidly, it is advisable to apply a suitable primer over the surface receiving the membrane to aid in the application of the first mopped-on coat of hot asphalt or coal-tar pitch.

[41] F. S. Merritt (Ed.), *Building Construction Handbook* (McGraw-Hill, New York, 1975), Ch 12, pp 9-12.

Material

Materials used in the membrane should meet the requirements of the following current ASTM standards:

Material	ASTM Standard[42]
Creosote Primer for Coal-Tar Pitch	D 43
Primer for Asphalt	D 41
Coal-Tar Pitch	D 450
Asphalt	D 449
Woven Cotton Fabric, Bituminous-Saturated	D 173
Coal-Tar-Saturated Felt	D 227
Asphalt-Saturated Felt	D 226

The number of plies of saturated felt or fabric increases with the hydrostatic head to which the membrane will be subjected. Five plies usually is the maximum used in building construction, although 10 or more plies have been recommended for pressure heads of 35 ft or greater. The thickness of the membrane crossing the wall footings at the wall's base should be no greater than necessary to reduce possible settlement of the wall due to plastic flow in the membrane materials.

SOGS Section No. 07140: Metal-Oxide Waterproofing

Metal- (iron) oxide-type waterproofing products may or may not be effective. Some data suggest that trowel-applied mortar coatings are highly water-resistant whether or not they contain iron.[43]

Coatings that contain iron are permeable to the water penetration by capillary action whether or not the water is under hydrostatic head.[44] Thus, this type of coating is not "waterproofed" in the full sense. Basically, iron-containing products should be avoided as waterproofing agents.

SOGS Section No. 07141: Metal Roofing and Siding, Plain

Uncoated galvanized-steel roofing and siding should be restricted to inland locations that have no industrial pollution in the atmosphere. Uncoated aluminized steel

[42]ASTM D 43-73, *Specification for Creosote Primer Used in Roofing, Dampproofing, and Waterproofing*; ASTM D 41-78, *Specification for Asphalt Primer Used in Roofing and Waterproofing*; ASTM D 450-78, *Specification for Coal-Tar Bitumen Used in Roofing, Dampproofing, and Waterproofing*; ASTM D 449-79, *Specification for Asphalt Used in Dampproofing and Waterproofing*; ASTM D 173-81, *Specification for Bitumen-Saturated Cotton Fabrics Used in Roofing and Waterproofing*; ASTM D 227-82, *Specification for Coal-Tar Saturated Organic Felt Used in Roofing and Waterproofing*; ASTM D 226-82, *Specification for Asphalt-Saturated Organic Felt Used in Roofing and Waterproofing* (ASTM Standards, 1983).

[43]F. S. Merritt (Ed.), Ch 12, p 3.

[44]F. S. Merritt (Ed.), Ch 12, p 3.

is reasonably acceptable for roofing and siding at coastal and industrial sites. However, it eventually will require coating. The surface preparation and inability to coat critical areas of the building components at this later date may lower the coating's effectiveness. If possible, only coated aluminized-steel roofing and siding that have been designed properly should be used in aggressive environments (see applicable paragraphs under **SOGS Section No. 13602** in this report).

SOGS Section No. 07142: Metal Roofing and Siding, Factory Color-Finished

The most acceptable material for roofing and siding at coastal and industrial locations is factory-coated aluminized steel (see applicable paragraphs under **SOGS Section No. 13602** in this report).

Coated galvanized steel is acceptable for exposed roofing and siding at locations with no salt or industrial atmospheric pollutants. Coated galvanized steel is equally acceptable for a building's interior surfaces regardless of location.

SOGS Section No. 07160: Bituminous Damp-Proofing

Bituminous cutbacks applied as "damp-proofers" on the inside faces of highly permeable unplastered masonry walls can be expected to blister and leak water through the coating.[45] It is advisable not to depend on these coatings to prevent leakage from wind-driven rain unless they are incorporated in the masonry or held in place with a rigid, self-sustained backing.

When the walls' inner faces are treated with bituminous coating, even though they resist wind-driven rain, water may condense on the warm side of the coating and the plaster may be damaged, whether or not the walls are furred. Bituminous coatings may be of benefit as a vapor barrier on furred walls if no condensation occurs on the warm side.[46]

SOGS Section No. 07600: Sheet Metalwork, General—Paint

Aluminum surfaces to be protected shall be solvent-cleaned and coated in one of two ways:

1. One coat of TT-P-645 zinc chromate primer and one or two TT-P-38 phenolic aluminum topcoats, depending on the severity of the environment.

2. One coat of TT-P-645 and one or two coats of exterior alkyd enamel such as TT-E-489 (for colors).

SOGS Section No. 07810: Skylights

Organic solvents such as ketones, esters, alcohols, ethers, and alkyl halides must not come into contact with the polymethyl methacrylate (PMMA) used to make

[45] F. S. Merritt (Ed.), Ch 12, p 7.
[46] F. S. Merritt (Ed.), Ch 12, p 7.

skylights.[47] (This could occur during cleaning when the protective covering is removed.) Equally important, skylights must be cleaned using equipment that will not scratch the plastic domes or panes. Deep scratches in the surface along with ultraviolet radiation reportedly can cause PMMA to undergo premature cracking failure.

SOGS Section No. 07840: Ventilators, Roof: Gravity-Type

All ventilators and associated hardware, components, and supports should be made of either a 3000- or 6000-series anodized aluminum alloy or aluminized steel when they will be exposed to either salt-laden, highly humid, coastal or industrial atmospheres. Galvanized-steel components should be avoided even for temporary structures in aggressive atmospheres because these facilities tend to become permanent at most military installations. Furthermore, aluminum-alloy and aluminized-steel ventilators from temporary buildings would be salvageable for use at another building when corrosion is present.

SOGS Section No. 07951: Calking and Sealants*

Although concrete structures can be coated easily, coating systems often fail because of sealant failure at the joints. Joint sealants for concrete panels should be mastics or elastomeric materials that are extensible and can accommodate panel movement. Recommended design joint widths for precast concrete panels are:[48]

Maximum Panel Dimensions (ft)	Normal Joint Width (in.)
5	0.38
18	0.5
30	0.75

Recommended maximum joint widths and maximum movements for various sealants are:[49]

Sealant Type	Maximum Movement, Maximum Joint Width (in.)	Tension and Compression (percent)
Butyl	0.75	+/- 10
Acrylic	0.75	+/- 15 to 25
One-Part Polyurethane	0.75	+/- 20
Two-Part Polyurethane	0.75	+/- 25
One-Part Polysulfide	0.75	+/- 25
Two-Part Polysulfide	0.75	+/- 25

[47] D. Knofel, p 95.

*Calks are used for fixed joints or those with slight movement; sealants are mainly used for joints where movement is anticipated.

[48] F. S. Merritt (Ed.), Ch 5, p 107.

[49] F. S. Merritt (Ed.), Ch 5, p 107.

A major limitation of butyl sealants and calks is their susceptibility to ultraviolet degradation.[50] This suggests they should not be used at most Middle East sites because of the bright sunlight.

Effective calking is important in preventing the ingress and accumulation of water in coated wood and cementitious substrates. Water or other moisture accumulation in these substrates must be minimized because it would ultimately cause the coatings to peel.

All sealants should be applied beginning at the bottom of the joint crevice and gradually building up to eliminate trapped air or voids.

[50] G. E. Weismantel (Ed.), *Paint Handbook* (McGraw-Hill, New York, 1981), Ch 5, p 11.

6 DOORS AND WINDOWS

SOGS Section No. 08105: Steel Doors and Frames

It is essentially impossible to ship, store, and install factory-coated steel doors without damage to the coatings. Rust that forms at damage sites (holidays) cannot be removed effectively in the field; touch-up coating is totally ineffective in preventing the recurrence of rust at these sites. Equally important, the coatings on steel doors are susceptible to in-service damage and associated rusting so that these doors require extensive maintenance. Therefore, when possible, steel doors and frames should not be used at installations in salt-laden, highly humid atmospheres.

When the proper sizes are available, FRP doors and frames should be installed.[51] All hardware for these doors and frames should be made of Type 304 austenitic stainless steel (see **SOGS Section No. 08201** in this report).

If steel doors and frames will be exposed to corrosive atmospheres, they should be zinc-galvanized at the factory and shop-primed with two coats of zinc-dust-pigmented primer meeting MIL-P-26915. After installation, the primer should be touched up as necessary and topcoated with two coats of aliphatic urethane coating meeting MIL-C-83286. (The aliphatic urethane coating, MIL-C-83286, also provides excellent resistance to ultraviolet light and abrasion.)

Nongalvanized steel doors that are factory-coated with a red oxide primer should be used only for building interiors or in dry, noncorrosive atmospheres.

SOGS Section No. 08201: Wood Doors—Topcoating

Exterior wood doors that will be topcoated should be factory-primed with a suitable coating (e.g., a quality alkyd enamel). If unprimed wood is exposed to high humidity or water (or the wood contains mildew), the entire surface area should be sanded to virgin material before priming. These precautions generally triple the life expectancy of the total coating system, which contributes to the door's service life.

SOGS Section No. 08300: Miscellaneous Doors

Aluminum-Alloy Doors

Aluminum-alloy doors, frames, and associated hardware installed in salt-laden, highly humid atmospheres must not contact steel, copper, brass, or any other materials higher in the noble series. Insulating dissimilar metals and alloys at these locations is not an acceptable option because it is difficult to insure that the work will be performed properly.

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[51] *Chem-Pruf Door Systems*, Technical Brochure No. 181-10 (Chem-Pruf Door Company, Brownsville, TX, 1981).

Fiberglass Doors

For highly humid coastal locations, consideration should be given to using FRP doors and frames with the associated hardware (hinges, screws, bolts, handles, kick plates, push plates, closers, thresholds, panic doors, and locksets) manufactured from Type 304 stainless steel.[52] The doors should be factory-mounted in the frames. FRP doors for which the inner cavities are filled with polyurethane foam should have an energy-efficient R factor of 9.* FRP doors are available with a flame spread rating of less than 25 according to ASTM E 84[53] and satisfy the self-extinguishing requirements of ASTM D 635.[54] These doors are especially advantageous for sanitary facilities because the sealed, nonporous outer resin does not support bacteria proliferation (see **SOGS Section No. 08201** in this report).

Steel Doors

Large steel doors and frames should be zinc-galvanized at the factory and coated with a zinc-dust-pigmented primer meeting MIL-P-26915. The doors and frames should then be factory-finished-coated with two coats of aliphatic urethane meeting MIL-C-83286. (The aliphatic urethane coating, MIL-C-83286, also provides excellent resistance to ultraviolet light and abrasion.) Qualified personnel should repair shipping, storage, and installation damage to the coatings on these large doors. This work involves proper surface preparation and the application of as many coats as were applied at the factory with sanding and feathering of the intermediate coats. The repair coating work can be done only after the doors and frames are installed. After repair, the entire door assembly should be given one coat meeting MIL-C-83286.

SOGS Section No. 08371: Aluminum-Framed Sliding Glass Doors

In aqueous environments, the aluminum-alloy frames for sliding glass doors should be insulated from zinc and galvanized steel in addition to other dissimilar metals or alloys. Aluminum is cathodic to zinc and metallic contact between the two dissimilar metals or alloys can accelerate corrosion of the zinc.** Corrosive destruction of the zinc on galvanized steel would eventually allow the aluminum to contact steel which would, in turn, cause galvanic corrosion of the aluminum.

If aluminum frames contact wet mortar, cement or concrete, the frames' contacting surfaces should be coated to prevent corrosion of the aluminum by the alkaline environment (see **SOGS Section No. 08520** in this report).

[52] *Chem-Pruf Door Systems.*

*$R = \frac{1}{C}$, where C is a material's conductance. C values are listed in *Handbook of Fundamentals*, published by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE).

[53] ASTM E 84-81a, *Test Method for Surface Burning Characteristics of Building Materials* (ASTM Standards, 1983).

[54] ASTM 635-81, *Test Method for Rate of Burning* (ASTM Standards, 1983).

**Zinc anodes are commonly used to cathodically protect underground and underwater aluminum structures.

SOGS Section No. 08510: Steel-Framed Glass Windows

Steel and galvanized-steel windows with associated hardware should not be exposed to salt-laden, highly humid or industrial environments. Only aluminum-coated steel framed windows and hardware should be used in severely corrosive environments.[55]

When nonaluminized steel (or galvanized-steel) frames will be used, the accompanying insect screens must not consist of aluminum or an aluminum alloy to avoid screen failure by galvanic corrosion.

SOGS Section No. 08520: Aluminum-Framed Glass Windows

If aluminum windows will be in direct contact with mortar or concrete that could become wet, the windows' contacting surfaces should be coated to prevent corrosion by the alkaline environment. Specifications currently require asphaltic varnish, TT-V-51, or bituminous coating, MIL-C-18480.[56]

SOGS Section No. 08710: Hardware, Builders' (General Purpose)

Because of the wide variety of types, styles, materials, and finishes found in the numerous items that comprise finishing hardware, it is advisable to retain a knowledgeable hardware consultant before making specifications in great detail, especially when major construction projects are involved.[57] This is important because items that are standard now may not be available later. The consultant should be familiar with the environments at Middle East coastal sites.

In general, only aluminum-alloy nails should be used on exterior finished surfaces at coastal locations. Galvanized-steel nails are reasonably acceptable for these surfaces if they will be coated before any significant rusting occurs. Uncoated steel nails should be restricted to indoor applications. Brass and/or heavy-plated-brass-on-steel screws should be used outdoors. All small bolts and nuts should be of cadmium-plated steel or brass.

Exterior locks and accessories should be brass, stainless steel, or heavy-plated-brass-on-steel.

Plastics should be avoided for protective door trim items such as kick plates. Instead, these accessories should be made of an austenitic-grade stainless steel, brass, or an aluminum alloy (see **SOGS Section No. 08201** in this report).

SOGS Section No. 08711: Hardware, Builders' (for Permanent Hospitals)

All hardware in high-use areas should be made of an austenitic-grade stainless steel. Stainless steel is essentially maintenance-free; furthermore, it does not provide a surface conducive to bacterial proliferation.

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[55]L. L. Shreir (Ed.), *Corrosion*, Vol 2 (Newnes-Butterworths, London, 1976), Ch 14, p 26.
[56]F. S. Merritt (Ed.), Ch 9, p 5.
[57]F. S. Merritt (Ed.), Ch 16, pp 1-8.

7 FINISHES

SOGS Section No. 09100: Furring (Metal), Lathing, and Plastering

Material

Neither gypsum nor anhydrite mortars should be used in areas of long-term dampness or permanently moisture-saturated air.[58] It is possible to use these materials in places with only periodically high relative humidities (e.g., in domestic bathrooms and kitchens) provided exhaust fans are installed and used regularly during activity in these areas. Alternatively, a water-vapor-impermeable coating can be applied to the plaster.

Ferrous-metal components that contact gypsum-containing plaster should be made of hot-dip-applied galvanized steel.

Plaster Curing

Before coating, plaster should be allowed to cure approximately 30 days at a minimum temperature of about 60°F.[59] Previously painted plaster surfaces in kitchens (and other areas on which oils and greases accumulate) should be cleaned with an aqueous solution of trisodium phosphate (TSP) and detergent; the cleaned surfaces should be freshwater-rinsed and allowed to dry before repainting.

SOGS Section No. 09180: Stucco, Cement

All galvanized steel (corner reinforcements) exposed to the exterior environment should be completely covered with stucco to prevent corrosion.

SOGS Section No. 09703: Conductive Sparkproof Industrial Resinous Flooring

Before applying conductive sparkproof industrial flooring, the concrete's surface must be prepared suitably to achieve adequate bonding. This must include removal of all hardening compounds, curing compounds, waxes, resins, laitance, glaze, efflorescence, and other materials such as products applied to the concrete to prevent marring during construction.[60]

Hard, smooth concrete surfaces must be opened by sand- or water-blasting or by acid-etching. Before etching or blasting, waxes and oils must be removed by alkaline cleaning and rinsing; heavy oils may have to be removed first with diesel fuel followed by alkaline cleaning and rinsing.

The concrete surface preparation and coating application must be closely monitored by inspection personnel. The coating manufacturer's specifications for all phases of the project must be followed strictly.

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[58] D. Knofel, pp 39-40.
[59] A. Banov, *Paints and Coatings Handbook* (Structures Publishing Company, Farmington, MI, 1973), p 124.
[60] G. E. Weismantel, Ch 11, p 21.

For areas with heavy traffic, a polyurethane binder should be considered for use as the conductive coating.

SOGS Section No. 09900: Painting, General

To be effective, coatings for corrosion mitigation must be properly (1) selected, (2) specified, (3) applied to adequately prepared surfaces/substrates, and (4) allowed to cure. In general, multiple coats (with the product for each coat furnished by the same coating formulator) are required to achieve the desired DFT; a waiting period between coats is usually required and there must be neither inadequate nor excessive wet-film application during a given coat. Onsite inspection by properly trained personnel is mandatory during all phases of a coatings project to ensure effective corrosion control.

Whenever possible, products and techniques used during a coatings project should be identified by standards and specifications that are well known to those who will perform the work. For example, specifications for steel surface preparation should be those defined by either the SSPC or the National Association of Corrosion Engineers (NACE). Visual standards available from both organizations provide an effective onsite way to insure that the surface preparations specified have been obtained.

Equally important is that abrasive-blasted ferrous-metal surfaces in coastal and other aggressive environments are primed before any "rust-bloom" forms. This requires that personnel prepare only as many abrasion-blast-cleaned surfaces as can be primed in a given work period. It should be noted that special products (e.g., silica sand or slag-based abrasives) are required for effective abrasive cleaning; do not use rounded sand (common in the Middle East) because the chloride content may be too high.

Rust-Inhibitive Coatings

"Rust-inhibitive coating" should be defined in the specifications as follows: "Rust-Inhibitive Coating--Coating used to prevent the corrosion of metals and, more particularly, specially formulated to prevent the rusting of iron, steel, and other metals."[61]

Red lead primer, TT-P-86, is the best primer for oil-based (enamel) paint systems used to protect atmospherically exposed mild steel. However, TT-P-86 has a lead content that far exceeds the 0.06 percent maximum lead content permitted by U.S. Public Law 94-317.[62] The limitation on lead-containing paints pertains only to all child-accessible interior and exterior areas of schools, nurseries, and family housing. Alternative nonlead-containing paints will either be more expensive due to greater material and/or labor costs (from the greater surface preparation needed) or will have inferior performance, especially when considering the hot, coastal exposure. Furthermore, TT-P-86 has shown superior performance for the maintenance painting of poorly prepared steel.

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[61] *Paint/Coatings Dictionary* (The Federation of Societies for Coating Technology, 1978), p 32.

[62] U.S. Public Law (PL) 94-317, *Public Health Service Act* (1976).

Quality Assurance Provisions

The requirements for testing procedures and reports must be detailed in the specification based on Method 1031.2 in the current Federal Standard 141. This method has been canceled with no superseding document cited; however, it will apply until notice is given to use another method. As stated, this method requires that:

> All tests performed shall be in accordance with applicable specifications. The contractor is cautioned to refer to and to comply with all modifications of the specifications cited in the contractual documents. If testing is not done by the contractor, it shall be his or her responsibility to furnish the designated testing facility with all pertinent contract information and modifications to make certain that the testing establishment is adequately informed to accomplish all tests and make accurate reports. Quantitative test results shall be reported to the same number of significant digits as are used in stating the requirements of that property in the commodity specification. Qualitative values shall be definitely stated. Results should not be reported simply as "complies" or "satisfactory," but in same manner as the requirements. The test methods shall be reported by reference to the applicable paragraph in the product specification or the method number when referenced to a Federal or other test method standard.

The cost incurred by the contractor for retesting in case the sample does not meet specifications should not be that now specified i.e., "$100/sample for retesting," since an average of $250 to $500 per sample is more in line with current laboratory charges. If the specification states that the cost of retesting will be deducted from the payment due the contractor, no fixed amount need be given. Costs will vary with time, type of paint, and laboratory used.

Exterior Enamels

Because of the pigment used, enamels colored international orange may contain much more than 0.06 percent lead. However, as previously mentioned, any coating with more than 0.06 percent lead is acceptable for use on items not normally accessible to children.

Exterior enamel, TT-E-1593, should be specified instead of TT-E-489 for all items exposed to intense sunlight. TT-E-1593 contains a silicone resin that provides better ultraviolet resistance than TT-E-489. Although it is expensive, the TT-E-1593 coating (or TT-E-490 semigloss) should outperform TT-E-489 in a desert exposure.

Concrete and Masonry Surfaces

Concrete surfaces to be painted shall have any surface glaze removed by light blasting or by scrubbing with a 5 percent solution of phosphoric acid. After the acid treatment, surfaces shall be rinsed with water and allowed to dry. Unless specifically authorized otherwise, interior walls and floors shall be sandblasted using only the wet or vacuum methods.

Plaster Surfaces

Plaster shall be allowed to age at least 30 days before painting, and this requirement should be added to future contracts. The aging process decreases surface

alkalinity when the plaster reacts with carbon dioxide in the air. This, in turn, decreases the chance of paint defects caused by too high a surface alkalinity.

Epoxy Coating

If required by the manufacturer, the pigmented epoxy resin shall be mixed with the hardener 1 hr before thinning or application.

Ferrous Surfaces

When using high performance coatings for immersion service (such as on water or petroleum oil liquid [POL] tanks) or to protect metals in highly corrosive environments, a near white metal blast cleaning (SSPC-SP 10) is usually considered minimum surface preparation.

Vinyl Paints

These paints should have excellent performance when exposed to atmospheres common in the Middle East. The current system given in Civil Works Guide Specification CW-09940, *Hydraulic Structures and Appurtenant Works* (August 1981), should be specified.

Formula VZ-107

This outdated specification has been known to cause problems in field application. Material applied satisfactorily should have no problems now; however, in the future, VZ-108, vinyl zinc primer from CW-09940 should be specified.

Formula V-766b; Formula V-102b; Ingredient Material for Special Paint

All of this information should be updated to conform to Guide Specification CW-09940 as stated above.

Painting Schedule

Exterior Ferrous Surfaces. For greater corrosion protection of nonshop-coated bare steel, TT-P-86 Type II should be specified rather than a ferrous metal primer. Power-tool cleaning that meets SSPC-SP 3[63] or brush-off blast cleaning that meets SSPC-SP 7[64] is considered minimum surface preparation when using this primer. Type I primer is acceptable with hand-tool cleaning that meets SSPC-SP 2.[65] However, the drying time for the Type I primer is much longer than for Type II, which may be disadvantageous at windy, dusty locations. For second and third coats, rather than an exterior oil paint, an exterior alkyd-enamel, TT-E-489 (TT-E-529 for semigloss) or an exterior silicone alkyd enamel, TT-E-1593 (TT-E-490 for semigloss) should be specified for much greater protection of steel in such environments. (See also previous comments under *Exterior Enamels*.) Areas with shop coating* damage should be power-tool-cleaned as per SSPC-SP 3 or brush-off blast-cleaned as per SSPC-SP 7 before the TT-P-86 Type II

[63]SSPC-SP 3, "Power Tool Cleaning" (SSPC, 1982).
[64]SSPC-SP 7, "Brush-Off Blast Cleaning" (SSPC, 1982).
[65]SSPC-SP 2, "Hand Tool Cleaning" (SSPC, 1982).
*A rust-inhibiting primer should always be specified as the shop coat primer.

primer is applied. The above surface preparation choices are considered minimum for the Type II primer. (See also previous comments under *Exterior Enamels.*)

Exterior Galvanized Surfaces. One of the following systems is recommended for exterior galvanized surfaces:

1. One or two coats (depending on exposure conditions) of zinc-dust primer (TT-P-641), or zinc-dust, chlorinated rubber primer (TT-P-1046).

2. A primer coat of TT-P-641 with two topcoats of exterior alkyd enamel. (See also comments under *Exterior Enamels.*)

3. Two coats of zinc-dust primer (MIL-P-26915) and two coats of aliphatic-urethane topcoat (MIL-C-83286).

For added adhesion over galvanized surfaces, the wash primer pretreatment DOD-P-15328, should be used.

Interior Concrete Masonry Units (With Porous Surfaces) and Interior Plaster: TT-P-29 latex-based paint is sometimes used as a primer to protect oil-containing coatings from attack by the alkali in concrete. (If too much moisture is present, the problem may occur anyway.) When alkali reacts with the oil in an oil-based coating, the coating becomes soft and slimy and brownish streaks can run down the walls. Since this condition is not remedied easily, a better solution is to use a complete latex coating system for concrete walls such as:

1. TT-P-29 as a primer and topcoat.

2. TT-P-19, exterior acrylic emulsion, as a primer and topcoat.

3. TT-P-29 as a primer with TT-P-1511, interior latex paint, for topcoating (TT-P-1511 Type I for semigloss, Type II for gloss).

If needed, a block filler can be used under any of these systems. If a moisture-resistant system is needed, use TT-P-95, chlorinated rubber paint, as primer and topcoat. If a heavy-duty system for a tile-like finish on concrete is needed, use TT-C-535, epoxy coating, as a primer and topcoat.

Interior Exposed Ferrous Surfaces, Shop-Primed. If less than 50 percent of the total shop-coated area has sustained damage, prepare and prime only the damaged areas rather than coating the entire surface with the ferrous metal primer. Select a ferrous metal primer that is compatible with the shop-applied primer and the specified alkyd-enamel second and third coats.

Exterior or Interior Surfaces Subjected to High Temperatures (up to 1400°F). A heat-resistant paint that performs well in corrosive environments is MIL-P-14105, heat-resisting paint (for steel surfaces). This coating is effective up to 1400°F.

Interior Concrete, Masonry in Areas of High Traffic or Those Requiring a High Degree of Sanitation. For the highest degrees of sanitation, two coats of TT-C-535 Type II epoxy polyamide should be applied. TT-C-535 will give a tile-like finish. A less expensive material that is not quite as hard as TT-C-535 is TT-P-2119, latex coating for high-traffic areas with flat and eggshell finishes.

8 SPECIALTIES

SOGS Section No. 10160: Metal Toilet Partitions

Metal toilet partitions and screens should be covered with factory-applied, tile-like coatings such as certain polyester-epoxy systems. These durable coatings are graffiti-, stain-, and scrub-resistant; when graffiti is marked on the tile-like finish, it is generally easy to remove without damage to the underlying coating.[66]

SOGS Section No. 10801: Toilet Accessories

If possible, all metal toilet accessories should be made of austenitic grade (300-series) stainless steel. Chromium-plated steel mirrors are not acceptable for highly humid toilet areas because of their susceptibility to pitting attack at holidays in the chromium plate. Metal mirrors should be made of an austenitic-grade stainless steel with a No. 8 finish.

SOGS Section No. 10910: Wardrobes

Natural-finish wooden wardrobes should be stained, filled, and given two coats of a single-package polyurethane transparent finish meeting TT-C-542. The surfaces should be sanded lightly (i.e., using No. 180 paper) after filling and between the two coats of transparent finish. The hinges, handles, and other hardware for these units should be either solid brass or bronze or steel with heavy-plated bronze or brass.

Clothes-hanging rods for all wardrobes should be made of an aluminum alloy. Galvanized-steel rods should not be used.

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[66] A. Banov, pp 28, 232-234, and 359-360.

9 EQUIPMENT

SOGS Section No. 11000: Miscellaneous Equipment

All motor vehicles (cars and trucks) that will operate at coastal locations should be rustproofed at the factory before overseas shipment. The rustproofing should include: (1) drilling enough access holes in the body to insure adequate drainage and that all hard-to-reach parts can be treated; (2) steam-cleaning;* (3) high-pressure application of a water displacement fluid into the body; (4) drying and high-pressure sealing of the cleaned surfaces with a suitable paraffin wax-bitumastic; (5) boroscope inspection to insure that all internal body compartments are coated; and (6) recoating if indicated by inspection.

SOGS Section No. 11225: Water Desalination Plant

Piping

Only ultraviolet-resistant materials should be used for pipes exposed to the atmosphere. If FRP and/or PVC piping is used, it should be protected from ultraviolet radiation.

Boiler Exhaust Stacks

Boiler exhaust stacks in corrosive environments should be protected with a high-temperature coating meeting MIL-P-14105 (effective up to 1400°F).

SOGS Section No. 11393: Sewage Lift Stations

Steel lift stations should be factory-finished internally and externally with three coats of MIL-P-24441 epoxy-polyamide and shipped in a way that minimizes damage to the coating. Alternatively, the exposed steel should be coated with a coal-tar epoxy, SSPC Paint No. 16 (CE No. C-200). The steel's external surfaces should have cathodic protection using sacrificial anodes (see **SOGS Section No. 16644** in this report) when the soil would be corrosive to steel (see **SOGS Section No. 15605** in this report). Similarly, the sewage sides of coated-steel lift stations should have cathodic protection. The cylinder design for steel lift stations should not include sharp corners (i.e., the interior wall-bottom transition should be rounded gradually and not at a 90 degree angle).

Concrete lift stations should be built using the guidelines in **SOGS Section No. 03316** of this report. All concrete surfaces that may be exposed to sewage must be coated with coal tar epoxy SSPC Paint No. 16.

All steel pipes and flanges inside the lift station should have electrical continuity and be coated. If the steel pipes and flanges are in contact with aggressive soil or sewage they should be coated with SSPC Paint No. 16 and cathodically protected using sacrificial anodes.

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*Usually not required on new vehicles.

Lift station pumps can be selected using the guidelines in SOGS Section No. 15140 of this report.

SOGS Section No. 11701: Casework, Metal and Wood (for Medical and Dental Facilities)

All steel cabinet bases to be placed on floors that will be scrubbed periodically with detergent and water should be elevated approximately 1 in. above the floor by support frames made of a nonmetallic material. This will prevent the steel from corroding due to water accumulation under the cabinets.

Outer surfaces of all coated-steel cabinets should be cleaned and waxed at least once a year.

Wooden casework should be finished as described for wardrobes (see SOGS Section No. 10910 in this report).

SOGS Section No. 13135: Double Corrugated Steel Arch Shelter Structures

All parts welded to the arch shall be repaired as specified in current SOGS Section No. 13135. All galvanizing that needs repair should be cleaned and touched up with DOD-P-21035, a cold galvanizing compound.

10 SPECIAL CONSTRUCTION

SOGS Section No. 13602: Metal Building*

Materials selection, protective coatings, and design are the primary factors to consider in achieving optimal corrosion control for metal buildings. Corrosion-mitigation recommendations are given for each part comprising the total building system.

Structural Steel (Beams and Columns)

The structural steel should be shop-primed with TT-P-664 or equal and then coated with a compatible coating system after erection (see **SOGS Section No. 09900** in this report).

For salt-laden, highly humid atmospheres, consider using galvanized-steel structural members.

Concrete Foundations

Concrete foundations and floors should be installed using the guidelines in **SOGS Section No. 03316** of this report.

Purlins

These should be made of galvanized steel when the building will be exposed to salt-laden, highly humid atmospheres.

Roof Panels

The exposed roof coverings should be made of aluminized steel meeting MIL-S-4174 Type II, which is factory-coated with an oven-baked fluoropolymer enamel such as Duranar 200 or Kynar 500. Factory-finished sheets shall pass the following tests as detailed in the current *SOGS Section No. 13602, Metal Building*: salt spray resistance, formability, accelerated weathering, chalking resistance and color change, humidity resistance, and impact resistance.

For construction in locations with frequent high winds and blowing sands, the coating must meet an abrasion resistance test: "When subjected to the falling sand test in accordance with ASTM D 968, the coating system shall withstand a minimum of 100 L [26.4 gal] of sand before the appearance of base metal."[67]

All metal edges of the siding or sheet-metal roofing shall be coated at the factory. If the siding or roofing sheet metal is cut during installation, all exposed edges must be patched with the manufacturer's recommended coating.

Roof panels should be "standing-seam" interlocking design and secured to purlins with a concealed structural fastening system to prevent the entrapment of moisture, sand, and dirt which would accelerate corrosion. The standing seams should have a

*Enclosed.

[67]ASTM D 968-81, *Test Method for Abrasion Resistance of Organic Coatings by the Falling Abrasive Tester* (ASTM Standards, 1983).

factory-applied, nonhardening sealant and should be locked or crimped together continuously by a mechanical method during erection. Roof panels with lap-side (longitudinal) joints and exposed structural fasteners are not acceptable. The concealed clips or backing devices used to fasten the roof panels to the purlins or secondary support members should be made of aluminized-steel.

Exposed fasteners should penetrate through the roofing surface only at roof panel terminations; these fasteners should be stainless steel or aluminum-alloy screws, bolts, or rivets with weather-seal washers.

Roof panel cross sections should be flat and free of cross-ribbing to eliminate the need for closure plugs at the eave, ridge, and roof penetrations. This will permit the roof surface to drain freely and prevent moisture, dirt, and sand from collecting.

Wall Panels

These panels should be made of aluminized steel meeting MIL-S-4174 Type II, which is factory-coated with an oven-baked finish. Finished sheets shall meet the same performance requirements as stated above for the roof panels.

The wall panel side seams should be interlocking, concealed, or tongue-and-groove type. Lap seams are not acceptable.

Wall panels should be fastened to their supports with clips, screws, or bolts inside the panel or concealed in the joint to keep the primary fasteners out of sight. Equally important, the panel edges should not be exposed to the outdoor environments.

Doors and Frames

When the proper sizes are available, doors and frames for coastal locations should be made of FRP. The hardware for these building components should be made of Type 304 stainless steel (see SOGS Section No. 08105 in this report).

Windows

Windows and associated components should be made of an anodized Type 6063 aluminum alloy.

Ventilators

Ventilators and associated components should be made of a suitable anodized aluminum alloy or aluminized steel (see SOGS Section No. 07840 in this report).

Gutters and Downspouts

Gutters and downspouts should be made of vinyl-coated aluminum.

Building Insulation

The vapor barrier for interior building insulation should be placed on the inside and all joints should be sealed properly. This barrier should have a permeability rating of 0.02 or less as stated by the manufacturer. Insulation should be fiberglass and must contain no leachable, aggressive ions such as chloride.

SOGS Section No. 15116: Welding Pressure Piping

Heavy-walled austenitic stainless steel (e.g., Types 302, 304, and 316) pipe containing more than about 0.03 percent carbon should not be field-welded when the end-product will be exposed to highly humid, salt-laden atmospheres. Field-welding produces "sensitized" areas in heat-affected weld zones; these areas are susceptible to intergranular corrosion.[68] When possible, only low-carbon (e.g., Types 304L or 316L) or stabilized (e.g., Types 321 or 347) grades of austenitic stainless steel should be selected for field-welding.

Weld-related crevices must be avoided in all stainless steel components. Low-oxygen crevices can corrode rapidly, especially when chlorides accumulate there.[69]

Residual stresses associated with welding austenitic stainless steels must be minimized or eliminated if the pipes may be exposed to chloride-containing aqueous environments at temperatures above about 150°F.[70] Otherwise, stress-corrosion cracking may occur. Proper system design can be an effective way to minimize residual stress.

Proper welding of stainless steel is critical to achieving a high-quality structure. Recent experience with construction welding of stainless steel at USAF Arnold Engineering Center in Tennessee resulted in extensive problems, even when correct specifications were given (AWS D10.4-79).[71] To help ensure effective welds, the contractor must follow specifications carefully and should avoid the following errors:

1. Weld spatter.
2. Embedment of material such as iron chips and rust.
3. Entrapment of slag in weld metal.
4. Colored markings in welds.
5. Splashing of paint near surfaces.

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[68] J. R. Myers, *Fundamentals and Forms of Corrosion* (JRM Associates, Franklin, OH, 1974), pp 48-53.

[69] H. Thielsch, *Defects and Failures in Pressure Vessels and Piping* (Krieger Publishing Company, Huntington, NY, 1977), pp 385-394.

[70] H. Thielsch.

[71] AWS D10.4-79, *Austenitic Chromium Nickel Stainless Steel Piping and Tubing, Recommended Practices for Welding* (American Welding Society, 1983).

11 MECHANICAL

SOGS Section No. 15140: Pumps: Sewage and Sludge

Most sewage can be handled by pumps that consist of ductile-iron shells and rubber- (e.g., neoprene-) coated internal components. The rubber linings, however, are susceptible to cutting damage by sharp edged items. This can lead to premature pump failure by corrosion. Heavy-duty pumps or pumps anticipated to operate on a near continuous basis, handling sewage and sludge containing large quantities of solids should be assembled using the materials below.[72] These materials may have a higher initial cost but are considered more cost-effective because of longer service life.

Component	Material
Stator Housing	Type 316 Stainless Steel
Pump Housing	Type 316 Stainless Steel
Junction Box Cover	Type 316 Stainless Steel
Impeller	Type 316 Stainless Steel
Shaft	Types 420 and 431 Stainless Steel
Cooling Jacket	Type 304 Stainless Steel
Wear Rings	
Rotating	Type 316 Stainless Steel
Stationary	Nitrile Rubber (40° IRH*)
O-Rings	Nitrile Rubber (70° IRH)
Grommets	Chloraprene Rubber (60° IRH)
Strainers	Type 316 Stainless Steel

The bottoms of the strainers should be factory-fitted with sacrificial zinc anodes to minimize crevice corrosion on submerged pumps' outer surfaces.

Materials that should be used to assemble sludge pumps include:

Component	Material
Impeller	Ni-Hard**
Casing	Ni-Hard
Casing Liner	Ni-Hard
Shaft Sleeve	Type 316 Stainless Steel
Stuffing Box	Type 316 Stainless Steel

If they will be submerged, these pumps also should have cathodic protection using zinc anodes.

Concrete foundations for the pumps should be installed using the guidelines presented in **SOGS Section No. 03316** of this report.

[72] *Flygt Product Education Manual* (Flygt Corporation, Norwalk, CT).
*IRH = International Rubber Hardness as defined in ASTM standards.
**Trade name of INCO for a cast iron with nickel (4.5 percent nickel, 3.3 percent carbon, and 2.1 percent chrome).

SOGS Section Nos. 15141 and 15143:* Pumps: Water, Centrifugal Pump; Water, Vertical-Turbine

The four basic forms of corrosion (i.e., galvanic, general, water-line attack, and cavitation)[73] that occur on water-side surfaces of pumps can be controlled best by judicious materials selection. Pump designs that minimize hydrodynamic pressure differences in the water system can help prevent cavitation damage (especially to the impellers).[74]

Material

Figure 2 gives basic information on selecting pump materials for seawater service. The following materials should be considered for pumps that will handle seawater.[75] These materials may have a high initial cost but are considered more cost-effective because of longer service life.

Pump Component	Preferred Material
Body	
Suction Bell	Copper Alloy No. 63000**
Shroud, Liner, or Case	Copper Alloy No. 63000
Discharge Column	Copper Alloy No. 63000
Deepwell Can	Copper Alloy No. 63000
Impeller	Copper Alloy No. 63000
Wear Rings	Ni-Cu Alloy No. 506
Shaft	Ni-Cu Alloy No. 400
Bolting	Ni-Cu Alloy No. 400

The same materials should be used for pumps that might handle waters containing more than 100 ppm chlorides (as Cl^-). Stainless steels such as Types 304 and Type 316 should not be used for seawater service unless the pumps will be operated almost continuously.

Pump components that will contact product water from desalination plants should be made of either aluminum bronze[76] or an austenitic grade of stainless steel such as Type 304L.[77]

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*These SOGS are combined because the corrosion control recommendations follow the same guidelines.

[73]T. E. Larson, "Corrosion in Vertical Turbine Pumps," *Water and Sewage Works*, Vol 94, No. 4 (April 1947).

[74]M. G. Fontana and N. D. Greene, *Corrosion Engineering* (McGraw-Hill, New York, 1978), pp 84-87.

[75]*Materials for Seawater and Brine Recycle Pumps*, Technical Brochure No. SM 11-76 (The International Nickel Company, Inc., New York, 1976).

**An aluminum bronze containing about 4.5 percent nickel to mitigate dealuminification.

[76]F. W. Fink, *Alloy Selection for Heat Exchanger Service in Seawater Conversion Plants*, Technical Report No. 704/6 (Copper Development Association, Inc., 1966).

[77]B. Todd, A. H. Tuthill, and R. E. Bailie, "Desalination--Lower Cost Water by Proper Materials Selection," paper presented at Third European Symposium on Fresh Water from the Sea, Dubrovnik, Yugoslavia, September 1970.

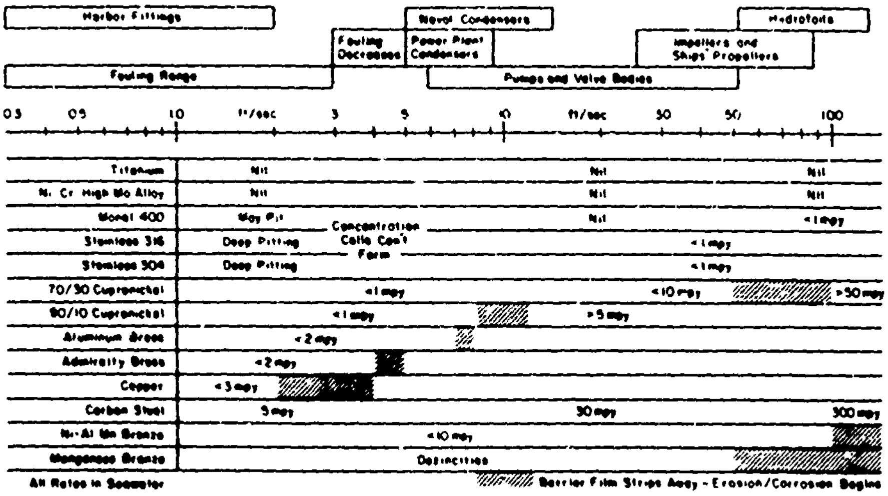

Figure 2. Effect of velocity on the corrosion and fouling of metallic materials in typical seawater, with corrosion rates given in mils/year. (From D. F. Hasson and C. R. Crowe, "Titanium for Offshore Oil Drilling," *Journal of Metals*, Vol 34, No. 1 [The Metallurgical Society of AIME, Warrendale, PA]. Used with permission.)

Water Treatment

The guidelines in **SOGS Section No. 16210** of this report should be followed in treating the cooling water for the pumps' internal-combustion engines.

Similarly, the guidelines in **SOGS Section No. 03316** should be followed for the concrete cast at the pump sites.

SOGS Section No. 15178: Pressure Vessels for Storage of Compressed Gases

Stainless steel Types 304 and 316 should be avoided for pressure vessels that will be exposed to salt-laden, highly humid coastal atmospheres unless the structures or welds can be solution-annealed after assembly to prevent intergranular corrosion.[78] If possible, stainless steel Type 304L or 316L should be used instead of the higher carbon versions. Alternatively, stabilized grades of austenitic stainless steels (e.g., Type 347 or 321) can be used. It is important to use proper electrodes and filler metal for welding austenitic stainless steels; the system used must not allow electrodes to be mixed during either shop- or field-welding. Halogenated products should not be used to clean stainless-steel pressure vessel interiors unless essentially all aggressive ions will be removed promptly during the cleaning process.[79]

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[78]J. R. Myers, pp 48-54.
[79]H. Thielsch, pp 376-420.

Stainless-steel pressure vessels should have no internal or external welding crevices.[80] They also should be essentially free from weld spatter.

Surface Preparation

Surface preparation for steel should be specified according to either SSPC or NACE criteria as follow:

	Specification	
Surface Preparation	SSPC*	NACE**
White Metal	SP 5	1
Near-White Metal	SP 10	2
Commercial Blast	SP 6	3
Brush-Off Blast	SP 7	4

Coating

Steel surfaces should be coated; however, stainless-steel surfaces should not be coated unless it is mandatory for color-coding. Over time, austenitic stainless steel will develop a tannish-yellow tarnish film at most coastal locations; this film should not be removed.

SOGS Section No. 15201: Water Lines

All underground metallic piping shall be coated and cathodically protected. All unwelded joints in piping shall be bonded for electrical continuity. Revised (Nov 1982) CEGS 16650, *Cathodic Protection System (Impressed Current)*, or CEGS 16642, *Cathodic Protection System (Impressed Current)*, should be used. Furthermore, ceramic anodes with performance equal to or better than silicon-iron can be used in impressed-current cathodic protection systems. The design and specifications of a cathodic protection system are referenced in Technical Manual 5-811-7, *Electrical Design and Cathodic Protection*. Ceramic anodes can be procured from APS Materials Inc., 153 Walbrook Ave., Dayton, OH, the exclusive licensed supplier for the Department of the Army (DA).

Asbestos-Cement and Concrete Pipe

Unlined asbestos-cement and concrete pipe should not be used to convey water that has an aggressive index (AI) less than about 10. The AI can be calculated using the expression:

$$AI = pH + \log (M \times CaH) \qquad \text{[Eq 1]}$$

where M is the total alkalinity and CaH is the calcium hardness, both expressed as mg/L. For comparison, distilled water generally has an AI of less than 7. Water treatment can be used to raise the AI to a suitably high value (about 11) so that the

[80] H. Thielsch, pp 370-420.
*SSPC *Painting manual, Vol 2—Systems and Specifications*, 2nd Ed. (SSPC, 1982).
**NACE Standard TM-01-70, *Visual Standard for Surfaces of New Steel Airblast Cleaned With Sand Abrasive* (1970).

cement will not leach; alternatively, vinyl-lined asbestos-cement or concrete pipe can be used.

Underground concrete and asbestos-cement pipe should be coated externally if the soil might be aggressive to these materials (see **SOGS Section No. 03316** in this report).

Cast-Iron and Ductile Iron Pipe

Polyethylene encasement, as specified, is considered acceptable by the American Water Works Association (AWWA) for gray and ductile cast-iron piping only and not for other buried pipe materials. Slip-on encasements used for the other metallic piping may actually accelerate corrosion, which then cannot be stopped effectively with cathodic protection. AWWA states the polyethylene (PE) encasement is beneficial for cast-iron piping in corrosive soils. However, the adequacy of PE encasement for protecting ferrous piping against corrosion is still being evaluated due to conflicting data in the literature. Water can leak in between the pipe and encasement, causing corrosion. Once the oxygen is consumed, the corrosion is expected to stop; however, conditions are now perfect for anaerobic bacteria to destroy the pipe.[81] With thick-walled cast iron, this situation can go undetected because a graphite skeleton will be present even after the iron dissolves. However, the situation can be critical, because the pipe would have no strength left and could not withstand a surge of pressure. The encasement also prevents future attempts to provide cathodic protection.

All buried metallic piping or conduits, except copper, should be coated with coal-tar enamel or tape meeting AWWA C-203; factory-applied and bonded PE, or factory-applied epoxy coatings (Federal Specification L-C-530, *Coating, Pipe, Thermoplastic Resin or Thermosetting Epoxy*). All field joints, valves, and similar items should be wrapped with hot-applied coal-tar tape as per AWWA C-203.

Note: hot-applied coal tar tape that meets AWWA C-203 is considered better than cold-applied protective tapes. However, the hot-applied tape's performance is very dependent on proper application. If there is concern for the quality of the labor available, the next best choice is a prefabricated cold-applied tape, 50 mils thick, meeting AWWA C-209. Tapecoat CT-10/40W, made by the Tapecoat Company, Evanston, IL, meets these requirements. Tape wrap should be applied with care because high winds can blow sand onto primer, embedding the sand between tape and pipe. All underground metallic piping, except copper, should be cathodically protected in addition to being coated.

PE-coated pipe (or the PE encasement sleeves) must be protected from prolonged exposure to sunlight. Also, all bituminous-coated piping and tanks must be covered before burial to limit ultraviolet exposure which can quickly damage the protective coating. As PE encased pipe fails, the replacement pipe sections shall be cathodically protected with a proper size anode.

Plastic Pipe

Plastic pipe has been used for years to transport potable water.[82] Both PVC and FRP piping are excellent choices. Unless it has special compounding or coating, plastic

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[81] C. K. Dittmer, R. A. King, and J. D. A. Miller, "Bacterial Corrosion of Iron Encapsulated in Polyethylene Film," *British Corrosion Journal*, Vol 10, (1975), pp 47-51.
[82] D. A. Chasis, *Plastic Piping Systems* (Industrial Press, Inc., New York, 1976), p 20.

pipe should not be exposed to the weather. One potential problem with PVC piping is that rodents have been known to gnaw through it (possibly attracted by the sound of moving water inside the pipe).

Valve Boxes

Although PVC valve boxes probably are most advantageous for Middle East water-distribution systems, their covers should be metal-impregnated so that the valve boxes can be located easily using a standard nondestructive test method should they become covered with sand or dirt.

Joints, Valves, and Similar Items

All field joints, valves, and similar items should be wrapped with hot-applied coal-tar tape meeting AWWA Standard C-203.[83]

SOGS Section Nos. 15240 and 15241:* Elevated Steel Water Tanks; Steel Standpipes and Ground Storage Reservoirs

Pipes and Fittings

All cast iron (with ductile iron preferred) pipes and fittings associated with the water storage facilities should be lined with cement mortar and coated on the outside surfaces. Polyethylene coated or encased pipes are also considered acceptable by the AWWA. Furthermore, all pipe joints and connections should be bonded with a proper size copper wire to insure the system's electrical continuity.

Exterior Surfaces; Elevated Steel Water Tanks

Exterior surfaces of steel water-storage structures should be coated. Steel surfaces placed in the water zone, water-fluctuation zone, or highly humid atmosphere above the water should be protected with a coating system. AWWA D-10284 is an acceptable guide for coating the water-side surfaces of steel water-storage structures, provided Inside Paint System Nos. 1 (three coats of MIL-C-4556), 2 (a five-coat vinyl system), or 4 (a four-coat vinyl system) are used.

Although AWWA D-102 Outside System No. 4 should perform acceptably, either Outside System No. 2 or 5 would provide longer protection. If System No. 4 is used, specify TT-P-86 Type II, and not Type III, red lead primer. Also, because of better weathering ability (resistance to ultraviolet degradation), either TT-E-1593 (gloss) or TT-E-490 (semigloss) silicone enamels should be substituted for the TT-E-489 enamel (gloss) topcoats.

Concrete Water-Storage Facilities Foundations and Supports

Concrete selection guidlines for foundations and supports for water storage facilities that will contact aggressive soils and/or waters can be found in SOGS Section

[83]AWWA C-203-78, *Pipeline Coatings and Linings* (AWWA Standards, 1978).

*These SOGS are combined because the corrosion control recommendations for steel and concrete water storage facilities follow the same guidelines. See SOGS Section No. 16641 for the cathodic protection of steel water storage facilities.

No. 03316 of this report. Fusion-bonded epoxy-coated steel reinforcements and anchors should be used if the concrete will contain more than about 1.2 lb chloride/cu yd during the facility's service life.

Concrete Water-Storage Facilities

Concrete water-storage tanks and reservoirs should be designed and constructed using the same guidelines described for concrete foundations and supports of steel storage facilities. The exterior surfaces (i.e., those exposed to the atmosphere) of concrete water-storage facilities should be protected with a "breathing"-type coating* such as a polyvinyl acetate latex; this coating's DFT must allow the coating to breathe. Otherwise, the coating will peel. The interior surfaces of a concrete water tank should not normally require coating. However, if a coating is desired, use a chlorinated rubber, TT-P-95 (Type I), or an epoxy polyamide, MIL-C-24441. All concrete surfaces must be fully prepared before coating is applied; this should include the removal of form-release agents, grease, oil, efflorescence, laitance, and glaze.[84]

Surface Preparation Requirements (Interior Painting)

This information applies to all steel water storage tanks, whether elevated, standpipe or ground storage reservoir. Applying a coating system over a commercial-grade blast-cleaning is not acceptable, nor is a pickling process of cleaning, SSPC-SP 8,[85] because these methods do not provide a blasting profile that increases the surface area to give the coating something to "bite into."

Regardless of the coating system being used, if the surface will be immersed in water, a *white-metal grade* of blast cleaning should be specified. The requirements in SSPC-SP 10 (1 Nov 82 revision) are considered acceptable, with SSPC-SP 5 even better. The CE requirement for near-white-metal blast cleaning could also be used (CW-009940).

Interior Tank Surfaces

Pretreatment-type vinyl coating systems are specified for CE Civil Works structures only in unusual circumstances. A major problem with the MIL-P-15328 pretreatment is that its potlife is only 8 hr after the acid component has been added. The coating looks the same after 8 hr, but will not adhere to surfaces. If the painter uses it anyway, the paint system will fail.

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*Water-vapor transmission coefficient allows water vapor to pass through without separating the coating from the substrate.

[84] A. Banov.

[85] SSPC-SP 8, *Pickling* (SSPC Standards, 1982).

A recommended replacement system is an epoxy coating, Inside Paint System 1, as given in AWWA D-102. This system lists three choices of material:

1. Paint 1--A three-coat system in accordance with MIL-P-24441.

2. Paint 2--A two-coat system in accordance with MIL-C-4556.

3. Paint 3--An equivalent system for which documentation (test results, service history, and toxicological data) has been provided by the manufacturer.

USA-CERL has worked with the two military specification epoxies and found them to give excellent performance in long-term water immersion. Both coating systems are available as standard products from various manufacturers (see their qualified products lists).

Other alternative systems include the vinyl paints from CW-09940. Systems 3, 4, and 5 may be specified for steel potable water storage tanks. Of the three, System 3, with the aluminum topcoats, is the most impermeable and should provide the greatest coating lifetime. The required surface preparation, coating thickness, and paint formulations for these systems are in CW-09940. The CE vinyl systems have proven to be at least equal, if not superior, to the vinyl systems in AWWA Inside Paint Systems 2 and 4.

When choosing between the epoxy and vinyl systems, it is important to note that an epoxy system probably is somewhat cheaper overall to apply, but that a properly applied vinyl system should give a longer lifetime. For highly corrosive environments in which a vinyl system would also be applied on the outside, vinyl also would be the logical choice for the inside.

If a vinyl system is specified for the exterior and the international orange color is needed, the following formulation can be used:

International Orange Vinyl Paint

Ingredient	Parts by Weight
Vinyl Resin Type 3	17.0
Diisodecyl Phthalate	3.5
Molybdate Orange Pigment	14.0
Caking Control Agent	1.0
Toluene	22.5
Methyl Isobutyl Ketone	21.0
Methyl Isoamyl Ketone	21.0
	100.0

The pigment and caking control agent shall be dispersed with a pebble mill or other approved method to produce a grind (ASTM D 1210)[86] of fineness no less than 6. Materials not shown in the formula will not be permitted. The finished paint shall reasonably approximate color number 12197 of Federal Standard 595. Samples of the

[86] ASTM D 1210-79, *Test Method for Fineness of Dispersion of Pigment-Vehicle Systems* (ASTM Standards, 1983).

finished paint submitted for approval shall include all ingredients, together with trade designations and producers.

All ingredients of this formula, except for the pigment and caking control agent, are the same as those used in vinyl formulation V-766e as described in CW-09940. Specifications for the pigment and caking control agent are:

1. Molybdate orange pigment shall conform to ASTM D 2218[87] and shall be the required shade.

2. The caking control agent shall be either Bentone 11-N produced by NL Industries or M-P-A produced by the Baker Castor Oil Co. (M-P-A 60 toluene or M-P-A 60 xylene can be substituted if the amount shown in the formula is increased from 1.0 to 1.6 percent and the amount of toluene is decreased by 0.6 percent).

All areas to be coated with this paint *must* be primed first with at least two sprays of an adhering vinyl such as V-766.

SOGS Section No. 15253: Water Softeners, Cation-Exchange (Sodium Cycle)

Material

Softeners (i.e., shells, pressure tanks, and mineral tanks) up to about 36 in. in diameter should be made of continuously wound FRP. The brine tanks (i.e., a brine-measuring tank combined with the salt storage tank) for these units should also be FRP.* The brine wells should be Schedule 40 PVC pipe, brine tubes and air checks should be Schedule 80 PVC pipe, and brine tank lids should be made of the same material as the tanks. Connecting pipes between the softener and the brine tanks should be made of Schedule 80 PVC. Internal components for the softeners (e.g., the manifold-lateral system and the disk strainers) should be made of PVC or PE.

The softener should be made of steel when its diameter exceeds about 36 in. The multicoat (three coats minimum), factory-applied, protective coating that should be applied to the softener interiors could be based on a baked phenolic-epoxy or a fusion-bonded epoxy system; the coating should have a DFT of at least 0.009 in. A sacrificial-anode-type cathodic protection system should be included as corrosion control for the softener interiors (see current *SOGS Section No. 16640, Cathodic Protection System [Sacrificial Anode]*). Similarly, brine tanks with diameters greater than 36 in. should be made of steel, coated internally, and cathodically protected. The anodes for all cathodic protection should be sized to provide enough current flow for at least 5 years. A coating system that has performed well in coastal environments for the outside surfaces of steel softeners and brine tanks includes an inorganic zinc primer (such as MIL-P-2688) and two topcoats of two-component polyurethane (such as MIL-C-83286). The primer for this system must be applied to a white-metal finish prepared in accordance with SSPC-SP 5 or NACE No. 1 (see **SOGS Section No. 15178** in this report).

[87]ASTM D 2218-67 (1979), *Specification for Molybdate Orange* (ASTM Standards, 1983).
*Small brine tanks can be made of PE.

Regardless of the softener size, the internal components, connecting pipes, and valves should be made of PE, PVC, red brass (e.g., copper alloy No. 23000), copper-nickel alloy (copper alloy No. 70600), or phosphor bronze (copper alloy No. 52100).[88]

If PVC or PE is used for the softening system's exterior, the softeners and brine tanks must be protected suitably to insure that they are not exposed to unacceptable levels of ultraviolet radiation.

Product Water

The product water from a sodium-zeolite softening system should be metered and fitted with an alarm system to insure that the resin is regenerated promptly. Magnetic-drive disk meters should be used for lines up to 2 in. in diameter; these meters should have hard rubber disks enclosed in a bronze housing. For product lines with diameters between 2 and 6 in., magnetic-drive turbometers should be installed. These should be made of the following commercially available materials:[89]

Component	Material
Housing	Type 316 Stainless Steel (on cast bronze)
Rotor and Nose Cone	Kynar
Magnet	Ceramic
Rotor Bearing, Spindle, and Endstone	Ceramic
Straightening Vanes	Type 316 Stainless Steel
O Ring and Tetraseal	Viton A or Buna N

SOGS Section No. 15254: (Electrodialysis and Reverse Osmosis) Water Treatment System(s)

Electrodialysis

Electrodialysis is not acceptable for military facilities in the Middle East because of the high operation and maintenance costs.[90] Reference to this water treatment process should be deleted from the current *SOGS Section No. 15254* until enough data are available to show that it is an acceptable, cost-effective water treatment technique.

Reverse Osmosis Units

Reverse osmosis (RO) units should have a modular design that will allow an existing system to be expanded easily by adding modules.

The RO system should include a clean-in-place (CIP) capability for membrane rejuvenation of each module (stack or permeators). The CIP tank should be FRP and the

[88]AWWA, *Quality and Treatment* (McGraw-Hill, New York, 1971), pp 369-371.
[89]*Industrial Turbo Meters*, Technical Bulletin No. Mt-4702 (Badger Meter, Inc., Milwaukee, WI, June 1980).
[90]M. J. Hammer, *Water and Waste-Water Technology* (John Wiley and Sons, Inc., 1975), p 264.

associated pipes should be PVC. In addition, the required pressure should be considered in the selection of materials for the associated pipes.

Reverse Osmosis Unit Material

RO units' modular tube housing, center tubes, and inlet/outlet pipes to the pumps should be made of PVC. The manifold on the modular housing should be made of Type 317L stainless steel, with the tie-ins between modules and manifold being polypropylene (PP).

Pump Materials

Suggested pump materials for handling the seawater (or brine recycle) and product water associated with the water treatment system are in **SOGS Section Nos. 15141 and 15143** in this report.

Piping and Valves

The performance of stainless steel Type 316L is marginal in nonflowing seawater; it is known to have concentration cell corrosion under this condition. Stainless steel Type 317L should be used for greater pitting resistance in the event of a system shutdown, where quiescent seawater may be present.

Product Water Quality

Product water hardness should be specified to a positive Langelier Index of +0.5* (refer to appendix B) to prevent internal corrosion of pipes by soft water.

SOGS Section No. 15261: Chlorine-Feeding Machines (Fully Automatic, Semiautomatic, and Nonautomatic)

Regardless of the control mode (i.e., automatic, semiautomatic, or manual), the chlorinator must be able to reliably deliver measured amounts of chlorine to the water being treated over an extended time with minimal routine maintenance. The water must contain the desired residual chlorine concentration at all times for effective chlorination.[91] Materials selection probably is the most important factor in chlorinator design and fabrication; wet chlorine gas, liquid chlorine, and chlorine solutions are unusually corrosive to most metals and alloys.

*A measure of saturation.

[91]E. J. Laubusch, "Chlorination and Other Disinfection Processes," *Water Quality and Treatment* (McGraw-Hill, New York, 1971), pp 158-224.

Material

Chlorinators that have been known to perform reliably for extended periods at various locations (including the Middle East) were made of:

Component	Material
Vacuum Regulator	
Body Assembly	ABS**
Flow Tube	Glass
Gaskets and O Rings	Viton
Springs	Tantalum Alloy
Diaphragm	CTFE***
Rate Valve	Silver
Rate Valve Seat and Sleeve	Silver
Inlet Valve Plug	Silver
Inlet Valve Seat	Teflon
Inlet Filter	Silver
Inlet Assembly	Aluminum-silicon Bronze/ Silver Plate
Vent Plug	Silver
Ejector/Check Valve Assembly	
Body Assembly	ABS
Diaphragm	Viton
Diaphragm Supports	CTFE
Spring	Tantalum Alloy
Check Valve Assembly	ABS
Valve Seat	Viton
Water Inlet	ABS
Solution Outlet	PVC
Miscellaneous Tubing Connections	ABS
Tubing	PE
Water/Solution Gaskets	Buna N

Only chlorinators that satisfy this basic materials list should be installed, unless data are available proving that other materials for these components have performed satisfactorily at the Middle East sites where the units will be installed. These materials are optimal for a highly corrosive environment; other less expensive materials may be considered. However, it is important to determine material specifications for specific applications.

Safety

A chlorine gas sensor should be installed in the chlorination room to monitor the area continuously for escaping gas.[92] The gas detector should be a relatively maintenance-free, solid-state device that can detect at least 1 ppm by volume chlorine in the atmosphere. In addition to the safety hazard, escaping chlorine must be detected because small amounts of this gas in the atmosphere can be especially corrosive to the

**Acrylonitrile butadiene styrene.

***Chlorotrifluorethylene.

[92] *Chlorine Gas Detector*, Bulletin A1.11C30.6 (Capital Controls, Colmar, PA, 1977).

metals and alloys it might contact. Early detection of escaping chlorine and correction of the leak(s) would preclude this possibility.

Maintenance

Routine plumbing associated with the chlorinator(s) should be done using the guidelines in **SOGS Section No. 15401** of this report. Field painting should be in accordance with current *SOGS Section No. 09900, Painting, General.*

SOGS Section No. 15263: Hypochlorite-Feeding Machines

Hypochlorinators (chemical metering pumps) should be made using the following commercially available materials:

Component	Material
Pump Head	PVC
Check Valves	Ceramic
Diaphragms*	Hypalon or Viton
Seals/Seats	Hypalon or Viton
Diaphragm Return Spring*	Titanium

Since hypochlorite storage tanks are generally of a small capacity, the tanks should be fabricated of PE. Coated and lined steel tanks should not be used. The hypochlorite solution lines and nozzles should be either PVC or PE.

Routine plumbing associated with chemical metering pumps should be done using the guidelines in **SOGS Section No. 15401** of this report.

SOGS Section No. 15302: Sewers, Sanitary Gravity

Pipe Material

The best options for gravity-type sanitary sewer systems are: vitrified clay pipe,[93] Type PSM PVC pipe manufactured in accordance with ASTM Standard Specification D 3034,[94] PVC-lined concrete pipe,[95] concrete pipe that has been specially lined or coated with an aggregate-filled coal-tar epoxy compound before the "green" concrete has cured,[96] and acrylonitrile butadiene styrene (ABS) pipe.[97] The previous materials may have a high initial cost but are considered more cost-effective because of longer service life.

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*When used.

[93] F. S. Merritt (Ed.), pp 21-30.

[94] *PVC Gravity Sewer Pipe for Sewer Systems*, Technical Brochure No. 40-34-24 (CertainTeed Corp., Valley Forge, PA, 1978).

[95] *Mainstay Composite Concrete Pipe*, Technical Brochure R2/64 (Ameron Corp., Brea, CA, 1964).

[96] *Mainstay Composite Concrete Pipe*, Technical Brochure No. ADUSS 20-3456-03 (Mainstay Corp., Roswell, GA, October 1969).

[97] R. H. Hansen, "Corrosive Waste Drainage System Design," *Heating/Piping/Air Conditioning*, Vol 55, No. 12 (December 1983), pp 71-76.

Unlined asbestos-cement, cast-iron, ductile-iron, and concrete pipe should not be used for gravity-type sanitary sewer lines if they carry aged (decomposed) sewage containing anaerobic and aerobic bacteria which can destroy the pipes inside crowns.[98] Conditions that promote premature aging of sewage include: (1) long sewer lines, (2) warm temperatures, and (3) low sewage flow rates.

The lined concrete pipes and fittings would need to have their exterior surfaces coated if they will be exposed to aggressive soils (see **SOGS Section No. 03316** in this report). Type V Portland Cement should be used.

Manhole Material

Consideration should be given to installing FRP manholes.[99] When concrete manholes are used, they should have steel-reinforced-fiberglass rungs (see **SOGS Section No. 15703** in this report) and should be coated externally if soil conditions warrant.

SOGS Section No. 15303: Forced Mains, Sewer

Mains

Cement-mortar-lined, ductile-iron pipe and fittings should be used for forced sanitary-sewer mains. When exposed to aggressive soils (see **SOGS Section Nos. 15605 and 15703** in this report), these pipes should be coated externally, wrapped with tape or enclosed with polyethylene. Joints and fittings should be bonded electrically and cathodically protected (see **SOGS Section No. 15201** in this report).

All cement-asbestos pipes used as forced sewer mains should be coated externally if they will be exposed to aggressive soils (see **SOGS Section No. 03316** in this report).

Pipes, General

Depending on the pipe sizes and pressures involved, consideration should be given to installing steel-reinforced concrete pipe that has been specially lined or coated with an aggregate-filled, coal-tar epoxy compound before the green concrete has cured.[100] This pipe will require an external coating if it will be exposed to aggressive soils.

Handling

All bituminous or plastic coated (e.g., PE, epoxy, etc.) piping, valves, and accessories shall be protected from prolonged exposure to sunlight. Even after being installed but before actual burial, these materials shall be kept covered.

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[98]NACE, "Concrete Sewers Should Last 100 Years," *Materials Protection*, Vol 5, No. 11 (November 1966), pp 13-14.

[99]*Fiberglass Flowtite Manholes*, Technical Brochure No. 5-PS-6455-A (Owens- Corning Fiberglass Corp., Toledo, OH, November 1984).

[100]*Mainstay Composite Concrete Pipe*.

SOGS Section No. 15304: Sewage-Treatment Plant; Wet-Burning Process, Prefabricated

Water- or sewage-side steel surfaces of the aerator, sludge-settling, and sludge-holding systems should be coated with an epoxy polyamide or, even better, an epoxy coal tar. SSPC Paint No. 16 (CE C-200) coal-tar epoxy is very effective for sewage treatment plants. CE E-303 (zinc-rich primer)/C-200 (coal-tar epoxy) combination is even more effective because the zinc dust in the E-303 can provide protection to the steel in case the coating system is damaged. The outside surfaces should be coated with an inorganic zinc and topcoated with an appropriately selected vinyl. (Inorganic zinc-rich paints are good coatings, but the finish coats often adhere with difficulty. Therefore, only a proven compatible system should be used. When possible, both the primer and topcoats should be from the same manufacturer.)

Copper Tubes

Copper and copper-based alloy tubes should not be used for components such as control lines at these plants because these materials are highly susceptible to corrosion by moist hydrogen sulfide.[101] Instead, these components should be assembled using Schedule 80 PVC pipes and tubes.

Concrete Pads

Reinforced-concrete pads for the plant should be installed using the guidelines in **SOGS Section No. 03316** of this report. Sewage pumps can be selected using the information in **SOGS Section No. 15140** of this report.

Galvanized Steel

Galvanized steel must not be used if it would contact sewage, treated sewage, or highly humid gases containing hydrogen sulfide. In such cases epoxy coated steel should be used as previously mentioned.

SOGS Section No. 15401: Plumbing, General-Purpose

Water Piping: Copper

Type L seamless copper water tube (i.e., copper alloy No. C12200) manufactured in accordance with ASTM Standard Specification B 88[102] should be used for potable hot-water lines for water temperatures less than 140°F.[103] Cold-water lines with diameters of 3 in. or less can also be copper. When the cold water conveyed is aggressive, even the larger diameter lines (over 3 in.) can be copper.

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[101] H. Leidheiser, Jr., *The Corrosion of Copper, Tin, and Their Alloys* (Krieger Publishing, Huntington, New York, 1971), p 93.

[102] ASTM B 88-83, *Specification for Seamless Copper Water Tube* (ASTM Standards, 1983).

[103] M. F. Obrecht and J. R. Myers, "How Corrosion Engineers Can Aid Designers of Potable Water Systems," *Heating/Piping/Air Conditioning*, Vol 45, No. 10 (September 1973), pp 70-73.

Domestic hot water circulating within buildings must not exceed 120°F and velocities of 5 ft/sec in order to mitigate erosion corrosion of the copper water tubes. If water must be circulated at higher velocities and temperatures, copper alloy 70600 shall be used. The flow velocity limits given above are more restrictive than those specified in Technical Manual 5-810-5;[104] however, they meet current industry standards.

Industry-standard design and workmanship are demanded when copper tube systems are used. Copper-tube domestic water systems can be expected to provide maintenance-free service for extended periods (up to at least 100 years) provided:

- Cut tube ends are reamed/deburred before joining.
- Unusually aggressive fluxes (especially acid-based self-cleaning types) and excessive amounts of flux should not be used during soldering because the acid will attack the copper.
- No globules of solder are left on the inside tube or fitting surfaces.
- The tubes are not dented, kinked, or bent severely during installation.
- There are no abrupt changes in tube diameter.
- Flared-tube fittings are installed properly.
- The copper tube system design does not include numerous changes in the flow direction over relatively short distances.
- The copper tube hot-water systems are not undersized (i.e., the flow rate of hot water does not exceed about 5 ft/sec routinely).
- The circulating hot-water pumps are not oversized.
- The temperature of the circulating hot water does not exceed 140°F routinely.
- The water pressure does not exceed 80 psig.
- Thermal insulations contacting the copper tubes and fittings that contain species which are aggressive to copper (e.g., chloride, ammonia, or sulfur-containing compounds) should not become wet.

General guidelines in the *Copper Tube Handbook*[105] should be followed when installing copper water tube systems.

Valves, Expansion Joints, Other Hardware

When the domestic waters conveyed have low temporary hardness, high chloride content, and pH above 8, brasses (e.g., yellow brass, 67Cu-33Zn alloy) will dezincify (Figure 3).[106] Dezincification of valve stems (the critical component with respect to

[104]Technical Manual (TM) 5-810-5, *Plumbing* (HQ, Department of the Army, 1 Nov 82).
[105]*Copper Tube Handbook* (Copper Development Association, Greenwich, CT, 1955).
[106]W. S. Holden, *Water Treatment and Examination* (Williams & Wilkins), pp 419-434.

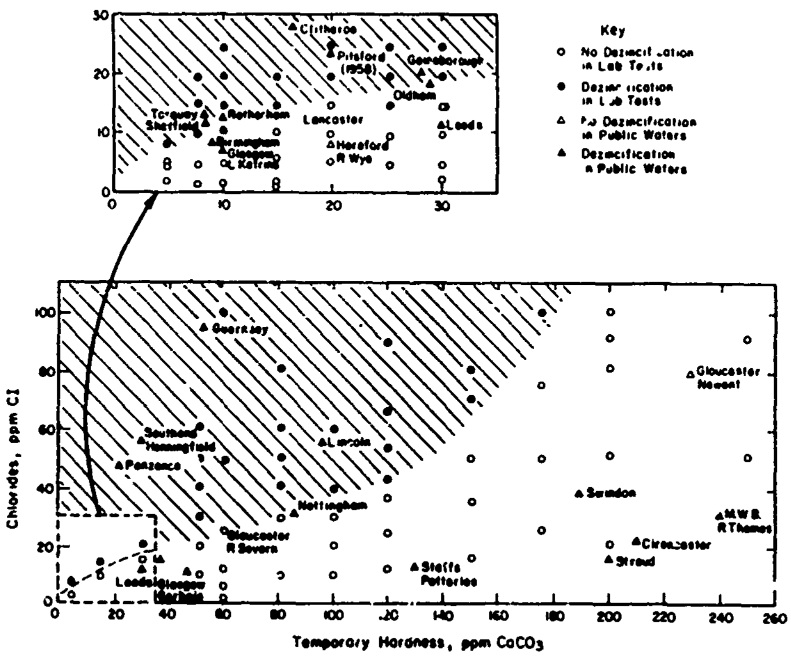

Figure 3. Effect of chloride content and temporary hardness of water on the occurrence of dezincification. (From W. S. Holden, *Water Treatment and Examination* [Williams & Wilkins]. Used with permission.)

corrosion in valves) can be mitigated effectively by specifying that the stems be made of a phosphorus or arsenic-inhibited silicon red brass.[107]

All valves, expansion joints, pumps, fittings, controllers, and other hardware used to install domestic water systems should be made of a suitable copper-based alloy. Valve seats in faucets should be made of Monel to prevent "wire drawing" (erosion corrosion common with conventional, plated-brass seats).[108]

Protective Coatings for Pipe and Fittings

See SOGS Section No. 15201 in this report.

Water Heaters

Small (less than about 120 gal) water heaters should be glass-lined and should have cathodic protection on the water side using sacrifical anodes sized properly for a 5-year life.[109] For water resistivities less than about 200 ohm-cm, the zinc anode material

[107] L. P. Costas, "Field Testing of Valve Stem Brasses for Potable Water Service," *Materials Performance*, Vol 16, No. 8 (August 1977), pp 9-16.
[108] J. R. Myers, pp 82-84.
[109] M. F. Obrecht and J. R. Myers, "Performance and Selection of Materials for Potable Hot Water Service," *Heating/Piping/Air Conditioning*, Vol 45, No. 9 (August 1973), pp 53-59.

should satisfy the chemical composition requirements of ASTM B 418 for high-purity zinc.[110] Magnesium-alloy anodes satisfying the chemical composition requirements of MIL-A-21412 should be used when the water resistivity exceeds about 2000 ohm-cm. All components of the pressure-temperature relief valve on hot-water heaters must be made of suitable copper-based alloys.

All large, steel water heaters should be cylindrical and lined internally with a hydraulic cement which is specified, applied, and cured properly.[111] A calcium oxide cement containing not more than 35 percent calcium oxide and not less than 25 percent silica should be used for waters with pH higher than about 7. An aluminum silicate cement that contains no free calcium oxide and not less than 25 percent silica should be used for soft waters or waters with a pH lower than about 7.

Cold-Water Storage Tanks

All cold-water storage ("house") tanks should have an internal coating and cathodic protection.[112]

Underground Piping

Underground ferrous metal and copper water pipes that are exposed to aggressive soils should have an external coating and cathodic protection (in this report, see **SOGS No. 15605** for ferrous metals and **SOGS No. 02455** for copper to identify aggressive soils for these materials).

SOGS Section No. 15402: Plumbing, Hospital

Potable Water

The corrosion-control recommendations in **SOGS Section No. 15401** of this report should be followed when specifying potable water systems for hospitals. Briefly, only copper or copper-based alloys are satisfactory for conveying Middle East waters in hospitals for which maintenance-free, long-lived systems are desired. Water storage tanks and water heaters should be lined or coated. For coating thicknesses less than 0.010 in., cathodic protection should be used to mitigate corrosion of the steel substrate exposed at holidays, which exist in almost all relatively thin, practical coatings. Similarly, all underground metallic pipes and tubes exposed to aggressive soils should have an external coating and cathodical protection.

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[110] ASTM B 418-80, *Specification for Cast and Wrought Galvanic-Zinc Anodes for Use in Saline Electrolytes* (ASTM Standards, 1983).

[111] J. R. Myers and M. F. Obrecht, "Corrosion Protection for Potable Water Storage Tanks: Part I--Linings," *Heating/Piping/Air Conditioning*, Vol 48, No. 12 (December 1976), pp 37-40.

[112] J. R. Myers and M. F. Obrecht, "Corrosion Control for Potable Water Storage Tanks: Part II--Cathodic Protection," *Heating/Piping/Air Conditioning*, Vol 49, No. 1 (January 1977), pp 61-66.

Distilled Water Piping

Distilled water at hospitals and laboratories should be conveyed by aluminum alloy systems[113] instead of tin-lined brass. Aluminum alloy tubing, piping, and valves are not affected much by distilled water, even at temperatures up to about 350°F. Furthermore, distilled water is not contaminated by contact with most aluminum alloys.[114] Aluminum alloys that can be used for distilled-water service include Types 1100, 3003, 5050, 5052, 6061, and 6063.[115] It is important that the water distribution systems which are designed and installed are totally of aluminum alloy; they must contain no sources of heavy metal (e.g., copper and iron) ions that could be deposited on the aluminum alloy and cause pitting attack.

There should be no major concern regarding exterior corrosion of the aluminum-alloy distilled-water lines unless they will be exposed to aggressive soils or wet, chloride-containing concrete. Aluminum alloys exposed to soils with a resistivity* of less than 1500 ohm-cm should have an external coating or wrapping and cathodic protection. With regard to cathodic protection, aluminum alloys must not be overprotected; otherwise, the high pH environment created will cause "cathodic corrosion" of these amphoteric materials. In general, aluminum alloys should not be polarized to potentials more negative than about -1.2 V when referenced to a copper-copper sulfate reference electrode.

SOGS Section No. 15496: Oxygen Piping System

Copper Piping Handling

The Type L copper water tubing used for oxygen-distribution lines should be delivered to the jobsite suitably cleaned inside for the intended application with the tube ends capped or plugged by the manufacturer. During installation, it is mandatory that no grease, oil, or other organic matter or excessive amounts of brazing flux be deposited on the inside surface. Cut tube ends must be deburred or reamed before joining. The braze alloy should have a melting temperature of at least 1000°F. After installation, the exterior surfaces of all tubes and fittings should be cleaned by washing with hot, fresh water. Guidelines in the *Copper Tube Handbook* should be followed to insure that oxygen distribution lines are installed properly.

Copper generally is not painted. However, to color code copper tubing, the following system is recommended:

1. Solvent-clean as per TT-C-490, method 2.

2. Apply pretreatment wash primer, DOD-P-15328.

3. Topcoat with appropriate alkyd enamel, depending on whether interior or exterior.

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[113] E. H. Dix, Jr., R. H. Brown, and W. W. Binger, "The Resistance of Aluminum Alloys to Corrosion," *Metals Handbook*, Vol 1 (American Society for Metals, Metals Park, OH, 1961), pp 925-926; H. H. Uhlig (Ed.), *Corrosion Handbook* (John Wiley and Son, Inc., New York, 1948), p 42.
[114] H. H. Uhlig (Ed.).
[115] E. H. Dix, Jr., R. H. Brown, and W. W. Binger.

Underground Conduit

Schedule 80 PVC pipe could be used for the conduit instead of cast iron when oxygen lines are underground. If cast iron must be used, the conduit system should be sealed to prevent water from reaching the inside surface (water could leak in through drainage associated with surface or subsurface irrigation). Leakage to the inside surface would eventually destroy the cast-iron conduit through galvanic corrosion (i.e., copper is cathodic to cast iron). Alternatively, a small-diameter, zinc-ribbon-type anode could be strung along the conduit's inside surface to provide cathodic protection when the conduit contains water. Externally, the cast-iron conduit should be coated and should have cathodic protection using sacrificial anodes (see **SOGS Section No. 16640** in this report) when it will be exposed to soils with resistivities less than about 5000 ohm-cm.*

SOGS Section No. 15408: Nitrous Oxide Piping System

Corrosion Mitigation

When the Type K copper water tube will be exposed to aggressive soils (see **SOGS Section No. 02455** in this report), it should have cathodic protection using sacrificial anodes (see **SOGS Section No. 16640** in this report). In the event the line's underground section is placed in a protective conduit, the guidelines in **SOGS Section No. 15406** of this report should be followed.

Grounding

The nitrous oxide line should not be grounded to the nearest domestic cold-water pipe, because that pipe could be some distance away, leaving the bond (wire) vulnerable to damage. Furthermore, even if the domestic cold-water pipe is nearby, this grounding technique would cause galvanic corrosion if the water pipe is a ferrous-based material. The nitrous oxide line should be grounded with the proper size copper rod and strap.

SOGS Section No. 15409: Vacuum Piping System

The semigloss white paint for color-coding copper vacuum lines should be applied using the guidelines in **SOGS Section No. 15406** of this report.

The copper tube system shall be installed according to industry standards. Cut tube ends must be reamed or deburred before joining. Unusually aggressive fluxes (especially certain self-cleaning types) and the application of excessive flux must be avoided during soldering and brazing. The inside tube or fitting surface must have no globules of solder/braze alloy or excessive flux, and flared-tube fittings must be installed properly. Equally important is that all residual flux on the outside surfaces of tubes and fittings be removed after soldering or brazing in order to avoid external corrosion of the copper in highly humid environments. Moreover, residual flux interferes with paint application onto the copper surfaces.

Copper tubes should be flared and copper tubes and fittings should be brazed or soldered using the guidelines in the *Copper Tube Handbook*.

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*Soil-box resistivity test using soil saturated with distilled water.

SOGS Section No. 15501: Sprinkler Systems, Fire-Protection

Corrosion Mitigation of Underground Supply Lines

Underground ductile-iron, large-diameter, supply lines to the fire-protection sprinkler system should be lined with cement mortar, coated externally, and cathodically protected when the soil resistivity is less than about 5000 ohm-cm.* It is especially important to protect the ferrous-based pipes under the building when aggressive soils are involved. Steel and galvanized-steel pipe should be restricted to diameters of 3 in. and larger (see **SOGS Section No. 15401** in this report). The large-diameter pipes in the building could be ductile iron lined with cement mortar when this product is available in the sizes required. When steel or galvanized steel is used for the larger diameter pipes, Schedule 80 pipe should be installed for a long-lasting system. The pipe diameters should be oversized to allow for the corrosion products that will build up when the steel or galvanized-steel pipes are exposed to aggressive water.

Materials

The material of choice for the fire-protection system is copper. Copper resists internal corrosion effectively, even in dry or alternatively wet and dry systems. Corrosion products do not build up inside the copper tubes and restrict flow; the Hazen-Williams coefficient** remains at a high value throughout the copper tube system's life. Furthermore, orifice-clogging rust particles do not become suspended in the water with copper systems.

Installation

Copper tube systems must be installed according to industry standards (see **SOGS Section No. 15409 and 15401** in this report). An acceptable, cost-effective fire-protection system can be designed and installed using the guidelines in the *Copper Life Safety Fire Sprinkler System Handbook.*[116]

Corrosion Mitigation of Standpipes and Water Storage Tanks

Steel standpipes and water-storage tanks associated with a building's fire-protection system should have an internal coating (see **SOGS Section Nos. 15240 and 15241** in this report) and cathodic protection (see **SOGS Section No. 16641** in this report).

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*Soil-box resistivity test using soil saturated with distilled water.

**A measure of friction within circular piping.

[116]*Copper Life Safety Fire Sprinkler System Handbook* (Copper Development Association, Inc., Greenwich, CT, 1973).

SOGS Section No. 15605: Fueling System for Motor Vehicles, Service-Station Type

All reinforcement steel in the concrete pads or deadmen (anchors) associated with both steel and FRP tanks should be coated with a fusion-bonded epoxy to prevent corrosion of the rebar which could lead to cracking of the concrete.

Existing tanks that develop leaks because of either internal or external corrosion can be lined in-place through an airless spraying process in which a relatively thick (about 0.030-in.) layer of glass-reinforced epoxy polyamide is deposited onto the clean inside surfaces.[117]

The dipsticks used to establish the amount of fuel in a tank should be fitted with rubber tips to insure that they will not damage the internal coatings.

Corrosion Mitigation of Underground Steel Storage Tanks

All underground steel tanks and pipes exposed to soils with a resistivity* of less than 10,000 ohm-cm should have an external coating or wrapping and cathodic protection for corrosion control.

The Steel Tank Institute (STI) recommends that steel tanks be fitted with a 0.25-in.-thick welded-in-place steel plate (i.e., splash plate) immediately below the extended fill pipes to mitigate tank wall erosion corrosion and galvanic corrosion at this location. The 8 by 8-in. spalsh plates should be factory-installed and -welded to eliminate crevices at tank/splash plate interfaces. Alternatively, the fill pipes can be fitted with splash deflectors.

Surface Preparation and Coatings for Steel Tanks

The exterior surfaces of underground steel tanks should be sandblasted to a minimum near-white metal blast finish (SSPC SP-10) and subsequently coated with a coal-tar epoxy, SSPC Paint No. 16 (C-200). This exterior tank coating should satisfy STI requirements for STI-P3 preengineered steel tank.[118] As an alternative, coal-tar primers and topcoatings of coal-tar compound, MIL-C-18480, can be applied to the exterior tank surfaces.[119] With this system, the steel need be prepared only to a commercial blast finish (SSPC-SP 6).

For maximum protection of a steel tank in very aggressive soil, an FRD resin coating should be specified. The coating system shall be factory-applied using fiberglass that conforms to MIL-Y-1140 and a grade of corrosion-resistant polyester resins meeting MIL-R-7575, grade B, for strength.

Tanks that have manways should be factory-coated internally with three coats of epoxy polyamide (i.e., MIL-C-4556) or polyurethane (i.e., MIL-P-23236, Type 1,

[117]*Matcote's Tank and Vessel Restoration Process* (Matcote Company, Inc., Houston, TX, undated).

*Determined by a soil-box saturation test using distilled water.

[118]*Petroleum Fuel Facilities*, Naval Facilities (NAVFAC) Engineering Command Design Manual No. 22 (U.S. Department of the Navy, August 1982), p 22-93.

[119]*Petroleum Fuel Facilities.*

Class 4).[120] Surfaces must be prepared in accordance with SSPC-SP 5 for a white-metal finish, and the coating must be applied and inspected properly. Internal corrosion by water that collects inside the tank bottoms can also be mitigated by installing zinc-ribbon-type anodes along the bottom interiors.

Hot-applied coal-tar tape (AWWA C-203), or cold-applied tape meeting AWWA C-209,[121] shall be field-applied to unprotected joints and fittings.

Since holidays will exist or develop on all practical coatings, coated underground steel tanks exposed to aggressive soils should have cathodic protection. Sacrificial anodes, either factory- or field-installed, are the most acceptable, cost-effective option for cathodic protection. When the anodes are factory-installed (as on the STI-P3 tanks), they must be oriented properly in the soil (i.e., away from the tank) to insure proper cathodic current distribution. The lead wire/tank connections for field-applied sacrificial anodes should be cleaned and coated with a bitumastic-type product (e.g., MIL-C-18480, coal-tar compound) after welding.

Above-Ground Steel Fuel Storage Tanks

Above-ground steel fuel tank exteriors should be primed with an inorganic zinc-rich primer and then topcoated with an appropriate vinyl coating. It should be noted that inorganic zinc primers can be hard to topcoat; that is, adhesion between the zinc primer and the topcoats can be very poor. A proven compatible system (primer and topcoats) must be used and specified as such. When possible, both primer and topcoating should be from the same manufacturer.

Alternatively, a CE coating system that should be very effective for outdoor exposure consists of E-303, (organic) zinc-rich primer, and V-766, white vinyl topcoating. The surface preparation should be near-white metal (SSPC-SP 10).

At a minimum, the tank should be sandblasted to commercial grade (SSPC-SP 6) and primed with a red-lead primer, TT-P-86 Type II, then topcoated with silicone alkyd enamel, TT-E-1593.

Corrosion Mitigation of Storage Tank Steel Pipes

Underground steel pipes associated with the storage tanks should have a coating or wrapping and cathodic protection when they will be exposed to aggressive soils. Continuously extruded PE coating systems are preferred for this purpose.[122] A reasonably acceptable alternative is a hot-applied coal-tar system meeting AWWA C-203. Field joints and any irregularly shaped fittings should be coated with hot-applied coal-tar tape meeting AAWA C-203; or, pressure-sensitive, organic-based (plastic) tapes meeting AWWA C-209 are acceptable when wrapped spirally and overlapped. The coated underground pipes must have cathodic protection using sacrificial anodes because the anodes attached to the tanks are designed to protect only the tanks. Further, on STI-P3 tanks, the pipes are insulated from the tanks intentionally to insure that the anodes installed provide adequate cathodic protection for the tanks.

[120] J. R. Myers, "Causes and Cures of Corrosion in Fuel Tanks," *Air Force Civil Engineer*, Vol 14, No. 3 (August 1973), pp 17-19.

[121] AWWA C-209, *Cold-Applied Tape Coatings for Special Sections, Connections, and Fittings for Steel Water Pipelines* (AWWA Standards, 1976).

[122] *Petroleum Fuel Facilities*.

Glass-Filament-Reinforced Polyester Resin Tanks

Although FRP tanks conforming to MIL-T-52777 are not adversely affected by native soils, gasoline, or diesel fuel, the steel pipes attached to these tanks must be protected against corrosion when they will be exposed to aggressive soils. In addition, the anchoring system (e.g., cable, hooks, and cable clamps) for these tanks are made of steel as are the manway covers and their associated attachment system (bolts and nuts). The steel used for the anchoring systems should be galvanized; this system should be coated with coal-tar compound, MIL-C-18480, and cathodically protected using sacrificial anodes (particularly important in areas with wet or damp, aggressive soils). The steel manways should have an external coal-tar coating, MIL-C-18480, and cathodic protection with sacrificial anodes.

Section No. 15609: POL and Diesel Storage Tanks, Controls, and Piping

POL Drain Tanks - Fiberglass

All underground exposed steel surfaces associated with the anchor system shall be coated with coal-tar compound MIL-P-18480 to prevent corrosion. When the site has a high water table or corrosive soil, tanks must have cathodic protection with sacrificial anodes (in addition to the coating).

Grounding Pits

A single alloy shall be used for the receptacle, stud, and pit cover; the best material is bronze. The container used to hold the coke breeze in place around the carbon grounding rod shall be of a hardened copper material.

POL Vent Pipe

The vent pipe that extends into the cavity between the steel liner and the concrete vault should be capped. This will prevent salt-laden moisture from entering this cavity and condensing on the uncoated steel liner.

SOGS Section Nos. 15651 and 15652:* Central Refrigeration System (for Air-Conditioning System); Refrigeration System

Tube and Fin Material and Corrosion Mitigation

Air-cooled condensers located within 1 mi of an open body of saltwater or within similar corrosive atmospheres shall be constructed of seamless copper tubes and copper fins bonded or soldered mechanically to the tubes. Aluminum fin/copper tube condensers are unacceptable for these conditions because of the potential for galvanic corrosion at the fin/tube interface.

Ideally, the condensing unit for roof- or foundation-mounted air-conditioning or refrigeration systems should be shielded from prevailing winds. Wind can blow salt and debris into the condenser coils (moisture traps), thereby promoting corrosion. If the unit

*These SOGS are combined because the corrosion control recommendations follow the same guidelines.

cannot be installed away from prevailing winds, a wall should be built around two sides; this wall shall be constructed with at least the minimum clearance recommended by the manufacturer. (Unit efficiency could be reduced greatly if the wall is placed too close.)

Other Component Material and Corrosion Mitigation

Aluminized steel could be used instead of galvanized steel or aluminum alloys for the ductwork associated with refrigeration systems.[123] Galvanized steel should not be used for the atmospherically exposed fans associated with the refrigeration equipment.

Corrosion-control recommendations for other components of refrigeration systems are in related SOGS in this report: (1) cooling towers (**SOGS Section No 15687**); (2) plumbing (**SOGS Section No. 15401**); (3) insulation (**SOGS Section No. 15703**); (4). painting (**SOGS Section No. 09900**); and (5) water-cooled condensers (**SOGS Section No. 15707 and 15708** for "closed" chilled water systems and **SOGS Section No. 15713** for "open-cycle" condenser water systems).

SOGS Section No. 15653: Air-Conditioning System (Unitary Type)

Corrosion-control recommendations for unitary-type air-conditioning systems are in other SOGS in this report as follow:

Component	SOGS Section
Cooling Towers	15687
Air-Cooled Condensers	15651; 15652
Ductwork	15802
Fans	15651; 15652
Insulation	15703; 15802
Closed-Water Systems	15707; 15708; 15802
Open-Cycle Water Systems	15713
Plumbing	15401

Aluminum fins on aluminum tubes, such as those manufactured by Carrier Corporation, should be specified for the condenser coils in window- or wall-type room air conditioners. Units with aluminum tube/aluminum fin construction will provide long service because they do not have the galvanic corrosion associated with copper tube/aluminum fin combinations.

When installed within 1 mi from open seawater or in other corrosive environments, direct expansion coils for air-conditioner systems (other than standard window- or wall-type room units or units under 5 tons) which draw outside air across the expansion (cooling) coils shall be constructed of seamless copper tubes and copper fins bonded or soldered mechanically to the tubes. Direct expansion coils made of aluminum fins on copper tubes are acceptable for systems that pull only recirculated room air across the coils.

[123] R. J. Schmitt and J. H. Rigo, "Corrosion and Heat Resistance of Aluminum-Coated Steel," *Materials Protection*, Vol 5, No. 4 (April 1966), pp 46-52.

SOGS Section No. 15687: Ice Plant

Water: Quality and Control

A basic prerequisite for producing quality ice is the availability of disinfected, clear, odorless, tasteless, iron- and manganese-free water that has a reasonably low mineral content. The water's bicarbonate hardness should be under 70 mg/L. Salt concentrations below about 170 mg/L are usually necessary for producing high-quality ice.[124] If chemically undesirable water is the only supply available, it should be treated to achieve the desired quality.

Brines are corrosive to ferrous-based materials (including galvanized steel) when the brines contain oxygen.[125] In addition, corrosion is aggravated if ammonia leaks into the brine,[126] so that brine solutions should be monitored for ammonia. When ammonia is found in the brine, the leak must be located and repaired immediately.

Corrosion of alloys exposed to brines also can be controlled effectively using inhibitors. According to the American Society for Refrigeration Engineers, the most effective inhibitor for brines is sodium dichromate; approximately 100 lb sodium dichromate/1000 cu ft brine should be maintained in the system.[127] In addition, enough sodium hydroxide should be added to convert the dichromate to neutral chromate; for neutral brines, approximately 27 lb sodium hydroxide/100 lb sodium dichromate is usually adequate. Meaningful testing should be conducted routinely to insure that approximately 1.6 g/L sodium dichromate is maintained in the brine. Sodium dichromate and caustic soda should be added as required. Alternatively, the brine can be inhibited with disodium phosphate;[128] however, sodium dichromate is reportedly more effective in mitigating external corrosion of the galvanized-steel ice cans and molds. Regardless of the inhibitor used, the brine should be treated by a qualified specialist.

Corrosion Mitigation

Since cooling water in the Middle East will most likely consist of brackish or once-through seawater, the corrosion mitigation techniques described in **SOGS Section No. 15713** of this report also apply to ice plants.

Cooling Towers

If cooling towers are used, they should be constructed of steel-reinforced concrete or ceramic. The steel reinforcements should have a fusion-bonded epoxy coating and the concrete should be coated where it might contact aggressive soils (see **SOGS Section No. 03316** in this report). In addition, concrete that contacts aggressive water (e.g., in a cooling tower basin) should be coated with an impermeable coating such as epoxy polyamide, MIL-P 24441, or chlorinated rubber, TT-P-95; general guidelines for coating concrete are in **SOGS Section Nos. 15240 and 15241** of this report.

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[124] Nordell, *Water Treatment* (Reinhold, New York, 1961), p 180.

[125] H. H. Uhlig (Ed.).

[126] *ASHRAE Guide and Data Book, Applications for 1966 and 1967* (ASHRAE, Inc., New York, 1968), p 837.

[127] F. N. Speller, *Corrosion: Causes and Prevention* (McGraw-Hill, New York, 1951), pp 40-409 and 635-637.

[128] F. N. Speller.

The open-cycle (recirculating) water for cooling tower systems should be treated to avoid unacceptable scale formation and corrosion.[129] When properly formulated organic phosphonates are used for scale and corrosion control (i.e., nonacid treatment), the cycles of concentration (C) should not exceed that predicted by the expression:

$$C = \frac{110{,}000}{Ca \times M}^{1/2} \qquad \text{[Eq 2]}$$

where CaH is the calcium hardness and M is the methyl orange alkalinity, both expressed in mg/L as $CaCO_3$.[130] Corrosion and scale are prevented by controlling blowdown and maintaining an adequate concentration of properly formulated organic phosphonate in the water. The cycles of concentration permitted in the water should be adjusted downward when necessary to insure that a maximum silica content of 150 mg/L and a maximum orthophosphate concentration of about 10 mg/L are not exceeded. The cycles of concentration permitted without organic-phosphonate treatment should be based on a saturation (Langelier) index of about +0.6 at 130°F (see appendix B). When sulfuric acid is added to mitigate scale formation, the maximum cycles of concentration allowed should be based on the solubility of calcium sulfate.[131] Open-cycle cooling tower waters should be treated with algacides and biocides, which should be slug-fed weekly. Unless the water is treated using organic phosphonates, corrosion inhibitors should be added to the open-cycle cooling water; inhibitors based on a solution that contains sodium molybdate and zinc chloride should be considered for this purpose. All open-cycle water treatment programs should be commissioned and supervised by a water treatment specialist with a proven success record in treating recirculating waters at the geographical areas where the cooling towers are located.

Steel Coatings

Steel coatings for the ice plant can be selected using information in the current *SOGS Section No. 09900, Painting, General.* Plumbing materials and practices should follow the guidelines in **SOGS Section No. 15401** of this report. Insulation applied to the exterior surfaces of steel pipe and copper tube must not be allowed to become wet; moreover, the insulation must not contain leachable species that are aggressive to commonly used piping materials (see **SOGS Section No. 15703** of this report). Steel brine tanks should have a suitable coating and cathodic protection using sacrificial zinc or aluminum alloy anodes (see **SOGS Section No. 16640** in this report).

SOGS Section No. 15701: Heating System: Steam, Oil-Fired

Treatment of Feedwater

Cost-effective corrosion and scale control for water-side surfaces of steam-heating systems can be achieved by proper treatment of the feedwater (before it enters the boiler) along with chemical additions to the boiler. In doing this, it is mandatory that

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[129] J. R. Myers.

[130] R. W. Lane and A. Kumar, *Selection of Cooling Water Treatments at Military Installations to Prevent Scaling and Corrosion*, Technical Report M-280/ADA087266 (USA-CERL, June 1980).

[131] *Drew Principles of Industrial Water Treatment* (Drew Chemical Corp., Boonton, NJ, 1977), p 126.

essentially all condensate (i.e., 95 percent or more) be returned to the heating plant for recycling. There must be no unauthorized use of steam (e.g., engine cleaning at motor pools) or excessive loss of product through leaks in the steam or condensate lines; these lines must be maintained adequately.

Initial Boiler-Fill Water

For low-pressure steam-heating systems, the initial boiler-fill water (as well as the makeup water when the system is operating) should be sodium-zeolite softened (i.e., have a hardness in the range of 0 to 1 mg/L as calcium carbonate). An effective system is to use untreated desalination plant product as the fill water. No water, however, should be introduced into the boiler until it has been established that the boiler, steam lines, and condensate return lines are free of installation debris, oil and grease, and other foreign matter. If water containing a bicarbonate alkalinity is used such that heating the water will produce 5 ppm carbon dioxide gas, for the boiler makeup, consideration should be given to installing dealkalizer. The dealkalizer should be of a size that can remove at least 90 percent of the methyl orange (M) alkalinity from the makeup water. Equally important is that the deaerator is vented properly.

Chemical Treatment of Boiler Water

Boiler waters must be treated chemically for both scale and corrosion control. A well established procedure for this involves adding certain polyphosphates (e.g., sodium tripolyphosphate for low-hardness waters), sodium sulfite, sodium hydroxide, and tannin to the boiler water. The total dissolved solids (TDS) content of the boiler water for a low-pressure system (i.e., less than about 200 psi) should be maintained at less than about 3500 mg/L.[132] The desired TDS content of the boiler water can be achieved through proper blowdown control. For normal operation, the boiler water should contain 30 to 60 mg/L phosphate ($PO_4^{=}$), 20 to 40 mg/L sodium sulfite (Na_2SO_3), and about 80 mg/L hydroxide (OH^-); it also should contain enough tannin to give it a "tea" color in accordance Bureau of Mines boiler water atreatment laboratory standard.[133]

In general, the sodium sulfite (an oxygen scavenger) and caustic soda (for alkalinity control) are fed continuously (as required) at the condensate tank or the storage section of the deaerator. Polyphosphates (for scale control) can be fed intermittently at the same location or can be slug-fed to the boiler water.

Chemical Treatment of Feedwater

If the feedwater (i.e., the makeup water plus the returned condensate) may release carbon dioxide in the boiler, a neutralizing amine should be added to the feedwater to mitigate general corrosion (carbon dioxide grooving) of the steel condensate-return lines. Amines that have been used routinely for neutralizing carbon dioxide in the condensate include morpholine and cyclohexylamine. The cyclohexylamine is often more desirable than morpholine, which is generally used in short-line systems. Sometimes a combination of the two amines is more advantageous. Filming amines such as octadecylamine are not recommended for condensate-return-line corrosion control at most military facilities because they require the plant operators' constant attention.

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[132]J. W. McCoy, *The Chemical Treatment of Boiler Water* (Chemical Publishing, New York, 1981), p 34.

[133]L. Goldman, *Boiler-Water-Treatment Manual for Federal-Plant Operators* (U.S. Department of the Interior, Bureau of Mines, 1951).

Condensed Steam Composition

For a properly treated, low-pressure steam-heating system, condensed steam leaving the boiler should have a pH of about 7.4 to 7.8, contain a trace to 1 mg/L carbon dioxide and essentially 0 mg/L oxygen, and have a specific conductance of less than 100 micro-mhos. A specific conductance greater than 100 micro-mhos indicates a carryover problem or excessive amounts of amine in the steam. pH values less than about 7.4 or greater than about 7.8 indicate inadequate or excessive amounts of volatile neutralizing amine in the steam.

The condensate's specific conductance should be the same as that measured for the steam. The condensate hardness should be near zero.

Effective water-side corrosion and scale controls for a steam-heating system require periodic chemical analysis of the boiler water, steam, condensate (at selected locations throughout the system), makeup water, and feedwater. Table 1 summarizes the tests for these products that should be conducted at least every 8 hr along with the limits prescribed for each. The tests must be done only by trained personnel. In addition, a representative of the organization furnishing the treatment chemicals should visit the heating plant at least every 2 months, conduct the tests identified in Table 1, and compare his or her data with those of the onsite water analyst. Any discrepancies between the two sets of data should be resolved immediately.

Corrosion Mitigation for Steel Storage Tanks and Pipes

Corrosion at underground steel fuel-oil storage tanks and pipes at the heating plant can be controlled using the same techniques recommended for tanks at the service-station-type fueling systems for motor vehicles (see **SOGS Section No. 15605** of this report). **SOGS Section No. 15605 also** provides recommendations for when underground FRP tanks are used to store heating oil. Above-ground fuel-oil storage tanks and pipes should be coated.

Boiler Storage

When a boiler is not in service, it must be laid up properly, or it will corrode at a relatively rapid rate. Generally, wet lay-up is used for short out-of-service intervals. Dry lay-up is always recommended for a boiler that will not operate for an extended time. The boiler manufacturer's recommended procedures for lay-up should be followed strictly. Alternatively, the representative of the organization furnishing the water-treatment chemicals could provide lay-up procedures.

SOGS Section Nos. 15702, 15705, 15711, and 15712:* Heating System: Forced-Hot-Water, Oil-Fired; Heating System: Forced-Hot-Water, High-Temperature Water Converter and Steam Converter; Hot-Water Plant and Heating Distribution System; and Hot-Water Heating System Wet Fill and Cap

Hot-water heating systems generally are categorized according to the temperature and pressure of the water conveyed. High-temperature hot-water (HTHW) heating

*These SOGS are combined because the corrosion control recommendations for "closed" hot-water heating systems are parallel.

Table 1

Tests and Chemical Control Limits for Maintaining a Properly Treated Low-Pressure Steam-Heating System

Test Site (Minimum for daily control)

S-1: Boiler water. Could be taken from continuous blowdown or from the water column.

S-2: Steam. Freshly condensed steam directly out of the boiler.

S-3: Condensate: Immediately after process or processes. Probably will include more than one test site.

S-4: Makeup water.

S-5: Feedwater. Collect sample after feedwater pump (i.e , just before boiler). Remember that raw water could leak into the feedwater if water-sealed pumps are used. However, water-sealed pumps are usually only used for 500 psi and larger boilers.

	Boiler (S-1)	Steam (S-2)	Condensate (S-3)	Make-up (S-4)	Feedwater (S-5)
Limits	1. $PO_4^{=}$ = 30 to 60 ppm[a] 2. Na_2SO_3 = 20 to 40 ppm 3. TDS ≤ 3500 ppm 4. 2P-M = OH 80 ppm as OH or 250 ppm as $CaCO_3$ 5. Organic tannin = "tea"	1. pH_{min} = 7.4 to 7.8 2. CO_2 = trace to 2 ppm 3. Spec. Cond. ≤ 100 mhos or have carryover	1. Hardness < 0 or have leak 2. Spec. Cond. ≤ 100 mhos (should be same as steam)	1. Hardness < 0 to 1 pmm if water is softened[g] 2. M Alk = 10% of M_{raw} if dealkyzed 3. Cl^- should be a constant value	1. Hardness < 1 ppm if softened
Tests	1. Spec. Cond. 2. P & M Alk. 3. Na_2SO_3 4. PO_4 5. Cl^-[b] 6. Color	1. Spec. Cond. 2. CO_2 3. M Alk[c] 4. Cl^-[d] 5. pH	1. Spec. Cond. 2. Hardness 3. M Alk 4. Cl 5. CO_2 6. pH[e,f]	1. Spec. Cond. 2. Hardness 3. M Alk[h] 4. Cl	1. Spec. Cond. 2. Hardness 3. M Alk 4. Cl

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[a]The better the control, the lower the $PO_4^{=}$ can be in the boiler.

[b]Cl^- of the boiler will depend on the water used.

[c]M Alk of condensed steam sample may be high from amines, but should be a stable figure.

[d]Cl^- in steam sample says "carryover."

[e]pH of condensed steam sample is measured for amine control.

[f]CO_2 and pH of condensate are measured for amine distribution.

[g]On specific condition of condensed steam sample, 1/2 of 1 percent of the boiler water spec. cond. is acceptable as carryover (about 35 mhos) and the spec. cond. contribution of CO_2 and the amines about 50 mhos; thus, the total ≤ 100 mhos.

[h]If SiO_2 content is high in makeup water, keep OH^- in boiler water >100 ppm as OH^-.

systems operate above 350°F and 450 psi; medium-temperature hot-water (MTHW) heating systems operate at 250 to 350°F with pressures above 30 psi; and low-temperature hot-water (LTHW) heating systems operate below 250°F at a maximum pressure of 30 psi.[134]

Regardless of the hot-water heating system's operating pressure and temperature, it is important that the initial fill (including that used during hydrostatic testing) and makeup water introduced have a quality approaching that of distilled or demineralized water (e.g., disinfected desalination plant product containing no suspended solids and with hardness near zero). This water must be treated chemically and circulated from the time it is introduced into the clean, disinfected, flushed system (i.e., it is mandatory to clean the water-side surfaces before the plant and distribution lines are placed in service).

LTHW

Corrosion and scale in LTHW systems should be controlled using the same techniques described for "closed" chilled-water systems (review **SOGS Section Nos. 15707 and 15708** of this report before continuing this section). The only difference between treating chilled-water and LTHW systems is the inhibitor concentration that should be maintained in the water continuously. Typically, the sodium nitrite concentration is maintained at 3000 to 4000 mg/L for closed LTHW systems operating at temperatures above 180°F; the concentration should be maintained in the 1500 to 2000 mg/L range for systems operating below 180°F.[135] When sodium nitrite-borax inhibitors are used to treat LTHW heating systems, they must be used in conjunction with a copper/copper-based alloy inhibitor such as sodium benzotriozole (BT) or sodium mercaptobenzotriozole (MBT). If sodium chromate is used to treat closed LTHW systems, the sodium chromate concentration should be maintained at 1000 mg/L for water temperatures below 180°F; the sodium chromate concentration should be at least 2000 mg/L when the operating temperature exceeds 180°F.[136] If small amounts of hard water might be introduced into the LTHW, the water treatment should include the addition of inhibitors for scale and deposit control. Scale inhibitors for LTHW heating systems include sodium polyacrylates, polymethacrylates, polymaleates, sulfonated polystyrene, carboxymethylcellulose, lignins, and phosphonates. A scale inhibitor that also functions as a dispersant should be considered for mitigating scale or deposit that might result from hard water ingress into the closed system.

MTHW

In general, the water in closed MTHW systems should be treated with an oxygen scavenger such as sodium sulfite while maintaining the water's pH in the 9 to 10 range through sodium hydroxide addition.[137] The residual sodium sulfite concentration maintained in the water should be about 20 mg/L. Only scale inhibitors and dispersants with thermal stability in the temperature range of operation should be introduced into the water (e.g., polyacrylates, polymethacrylates, and phosphonates).

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[134] R. T. Blake, *Water Treatment for HVAC and Potable Water Systems* (McGraw-Hill, New York, 1980), pp 143-153.
[135] R. T. Blake.
[136] R. T. Blake.
[137] R. T. Blake.

HTHW

The water in closed HTHW systems should be treated with hydrazine or sodium sulfite on conjunction with enough sodium hydroxide to maintain the water's pH in the 9.0 to 9.5 range. The sodium sulfite oxygen scavenger is more effective for HTHW systems that contain copper-based alloys. In general, a residual sodium sulfite concentration of about 20 mg/L should be maintained in the water. Only thermally stable scale inhibitors and dispersants should be added to HTHW systems.

Closed System Testing

The initial chemical dosage (I) for a closed hot-water heating system should be estimated using the expression:[138]

$$I = (P/120)(V/1000) \qquad \text{[Eq 3]}$$

where P is the desired dosage in milligrams per liter, V is the total system volume in gallons, 120 and 1000 are conversion factors, and I is measured in pounds.

Adequate testing is required to insure that the proper inhibitor concentrations are maintained in closed hot-water heating systems. "Adequate" means initially and at least every 8 hr immediately after upset conditions, or weekly for systems with low makeup rates. Chemicals must be added to closed hot-water heating systems in accordance with the results of these analyses. Only trained analysts should conduct these tests. When the amount of makeup water added to a closed system is known (e.g., through metering), the amount of inhibitor needed (F) can be reasonably estimated using the expression:

$$F = (P/120)(M/1000) \qquad \text{[Eq 4]}$$

where P is the desired dosage in milligrams per liter, M is the makeup water in gallons, and F is measured in pounds.

All testing must be conducted using accepted analytical methods. The onsite analysts' test data should be compared at least every month with those obtained by a representative of the organization furnishing the treatment chemicals. Any discrepancies between the two data sets should be resolved immediately. Chemicals should not be purchased from an organization that does not provide this service.

Regardless of the chemical(s) used, closed hot-water heating systems must be kept very clean. Sidestream filters often are used to achieve this objective.

Hot-Water System Components

All expansion tanks associated with hot-water heating systems should be nitrogen-blanketed to prevent oxygen ingress when the water contracts during cooling periods. Furthermore, maintenance personnel must insure that not too much water is lost because of leaks or the unauthorized use of hot water. Makeup water should be metered.

Hot-water heating system distribution lines should be insulated externally with inert, nonaggressive materials (see SOCS Section No. 15703 in this report). The insulation should never be allowed to become moist.

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[138] *Drew Principles of Industrial Water Treatment*, pp 147-151.

Equally important is that water-absorbing (e.g., asbestos) gaskets not be used in hot-water heating systems. These materials produce unacceptable concentration-cell corrosion.

Copper and copper-based alloy tubes and fittings must be installed according to industry standards (see **SOGS Section No. 15401** in this report). Steam-converter-type heat exchangers should have copper alloy No. 70600 tubes and the steam used in these generators must be treated properly (see **SOGS Section No. 15701** in this report); all steam condensate and the steam used in these generators must be treated properly (see **SOGS Section No. 15701** in this report); all steam condensate must be returned to the steam-heating plant.

Hot-Water Heating System Storage

Hot-water heating systems must be laid up properly when they are not operating to prevent unacceptable pitting corrosion on the water side. Lay-up recommendations from the hot-water generator's manufacturer should be followed strictly. As an alternative, the representative from the organization furnishing the water-treatment chemicals could provide lay-up instructions.

Corrosion Mitigation of Steel Heating-Oil Storage Tanks and Pipes

Corrosion of underground steel heating-oil storage tanks and pipes can be controlled using the same procedures described for the tanks and pipes at service-station-type fueling systems for motor vehicles (see **SOGS Section No. 15605** in this report). **SOGS Section No. 15605 also** provides recommendations for when FRP tanks are used to store heating oil. Above-ground tanks and pipes should be coated externally.

SOGS Section No. 15703: Heat-Distribution Systems Outside Buildings

Casings

All underground steel heat-distribution casings exposed to soils with a resistivity* of less than 10,000 ohm-cm should have an external coating and cathodic protection (e.g., see current *SOGS Section No. 16640, Cathodic Protection System [Sacrificial Anode]*).[139] Similar corrosion control is required when gray cast iron and ductile iron are exposed to soils with a resistivity of less than 5000 ohm-cm, especially when the soils have a high sulfate content. When the soil-box-determined resistivities exceed these values, the services of a qualified (e.g., NACE-certified) corrosion specialist who has at least 5 years' experience in underground corrosion control are needed to determine the requirements.

Casings should be shop- or factory-coated. All slag and sharp protrusions resulting from field welding should be removed before the girth-weld areas are coated or encapsulated. Soil-side coatings should be inspected for holidays using detectors of suitable voltage; all coating defects should be field-repaired before the casings are covered with rock-free, fines and/or soil.

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*Determined by soil-box saturation test using distilled water. Soil samples for this test should be collected at the casing depth.

[139] J. R. Myers and M. A. Aimone, *Corrosion Control for Underground Steel Pipelines: A Treatise on Cathodic Protection* (JRM Associates, Franklin, OH, 1977), p 25.

Insulation inside the casings should contain few, if any, leachable aggressive ions such as chloride.[140] Heavy metal (e.g., copper and iron) ion-containing insulation should also be excluded when an aluminum jacket is used to protect the above-ground heat distribution pipes. Aluminum jackets must be insulated electrically from the heat-distribution pipes. In addition, the aluminum alloy used for the thin (0.016-in.-thick) above-ground jackets should have proven corrosion resistance in humid, dusty, salt-laden, coastal environments or where the atmosphere can be contaminated with industrial pollutants.

Installation of Heat-Distribution Systems

Immediately after installation of the heat-distribution system (but before the system's underground section is covered with soil or sand), warm air should be forced through the insulation-containing annulus from one end of the system until no condensation appears on an ambient-temperature mirror (shaded from the sun) located at the other end. This will insure that the insulation is dry. Concurrently, it would be desirable to force a gas such as helium through the insulation zone to locate (using a suitable leak detector) and repair any leaks in the casings. It cannot be overemphasized that the insulation must remain dry.

FRP Pipes

Foamed polyurethane-insulated FRP condensate or hot-water pipes should not be used if there is any possibility they will be exposed to thermal environments exceeding about 250°F. Temperatures in excess of 250°F, even for short periods of time, could cause dimensional instability and eventual failure of the material.

Casing Coating

For aggressive soils, zinc-coated steel casings should not be considered an equal substitute for organically coated, cathodically protected steel lines. All zinc-coated steel casings arriving at a jobsite should be shop-coated before installation; moreover, cathodic protection should be applied during installation if the soils are corrosive to steel.

SOGS Section Nos. 15707 and 15708:* Chilled-Water Distribution System Wet Fill and Cap; Chilled-Water Plant and Distribution System

The metallic pipes and other water-side equipment in closed water systems theoretically should not corrode after the dissolved oxygen introduced with the initial fill is consumed by corrosion. However, truly closed chilled-water systems almost never exist.[141] Makeup water containing dissolved oxygen is added routinely to essentially all

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[140] J. F. Delahunt, "Corrosion Control Under Thermal Insulation and Fire Proofing," *Bulletin of the Institution of Corrosion Science and Technology*, Vol 20, No. 2 (May 1982), pp 2-7.

*These SOGS are combined because the corrosion control recommendations for both are identical.

[141] S. Sussman, "Is Your Closed Circulation Water System Really Closed?" *Heating, Piping, and Air Conditioning* (April 1965).

closed systems. This means that closed chilled-water systems must be treated chemically to control corrosion.[142]

Initial Fill and Makeup Water

The initial fill and makeup water introduced into a chilled-water system should have a quality approaching that of distilled or demineralized water (e.g., disinfected desalination plant product containing no suspended soilds). This water must be treated chemically and circulated from the time it is introduced into the cleaned, disinfected, flushed system (i.e., it is mandatory to clean water-side surfaces before the plant and distribution lines are placed in service).

Chemical Treatment of Water

The most acceptable, cost-effective corrosion control for a closed chilled-water system can be obtained by using a sodium nitrite-borax inhibitor. The nitrite mitigates corrosion of the steel and cast iron and the borax keeps the water pH high enough that the nitrite can function. Typically, the water's pH should be in the 8 to 9 range. Since nitrite does not inhibit corrosion effectively for copper or copper-based alloys, the nitrite-borax inhibitor should be formulated with BT or MBT when these nonferrous materials form part of the chilled-water system. It is advisable to obtain the nitrite-borax-BT/MBT inhibitor from a reputable water-treatment chemical supplier rather than purchasing the individual chemicals and mixing them onsite.

Theoretically, 500 mg/L sodium nitrite ($NaNO_2$) are required to protect steel and cast iron. In practice, approximately 1400 mg/L sodium nitrite are used because nitrite is an anodic inhibitor (potentially dangerous) and a certain supply must always be present in the water. It is important, however, not to introduce too much inhibitor into the water because this could potentially result in rapid deterioration of any amphoteric metals and alloys in the system (e.g., solder). In addition, oxidizing biocides must not be used in conjunction with the nitrite-borax inhibitor because they oxidize the nitrite to ineffective nitrate.

Alternatively, closed chilled-water systems can be treated using chromates (e.g., 500 mg/L sodium chromate with the water pH maintained in the 7 to 9 range using sodium hydroxide).[143]

Regardless of the chemical used, the closed chilled-water system must be kept very clean. Sidestream filters often are used at chilled-water plants to achieve this objective.

Microbiological problems in closed chilled-water systems are rare. When these problems do occur, however, they are corrected easily using biocides. One advantage of treatment with chromate is that this inhibitor is toxic to many forms of biological growth.

The specific conductance of the nitrite-borax inhibited, chilled water should be measured every 8 hr after the water is first treated. Concurrently, the water's sodium nitrite content should be measured. Typically, an adequate concentration of inhibitor (i.e., about 1400 mg/L sodium nitrite) is reached when the untreated water's specific

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[142]S. Sussman and J. B. Fullman, "Corrosion in Closed Circulating Water Systems," *Heating and Ventilating* (October 1953).
[143]R. T. Blake.

conductance is increased by about 2700 micro-mhos. Once the system has stabilized with regard to these analyses, the test interval can be increased to 24 hr and, eventually to 1 week. If an upset occurs in the system (e.g., an unusual amount of makeup water is added or there is a major loss of conductance and/or nitrite), it will be necessary to return to the original 8-hr (or even more frequent) analysis program.

Chemical Feed Systems and Water Analysis

Chemical feed systems must be able to introduce corrosion-control chemicals into the water according to the amount needed; this amount is established by the chemical analysis program.

It is also advisable to have a representative of the chemical supplier visit the chilled-water plant at least monthly to analyze the water and compare his or her results with those obtained by the plant chemist. Any discrepancies between the two data sets should be resolved immediately. Chemicals should not be purchased from a supplier who does not provide this service; furthermore, chemicals should not be purchased from a supplier who does not provide test kits for sodium nitrite analysis.

SOGS Section No. 15713: Open-Cycle Condenser Water System

Material: Condenser Tubes

Seawater and brackish water are the most suitable options for condenser cooling at most Middle East sites. The condenser should be cooled using a once-through system (i.e., the open-cycle cooling water is filtered, pumped to the condenser, passed through the condenser tubes, and then discharged). Since chloride-containing, aerated sea and brackish waters are aggressive to many materials, the condenser tubes should be made of a suitable copper-based alloy, titanium, or a titanium alloy. copper alloy 70600 can be used for condenser tubes when the seawater flow rate does not exceed about 7 ft/sec and the product conveyed is not contaminated with sulfur- and/or ammonia-containing compounds. Commercial purity-grade titanium or Ti-Code-12 titanium alloy tubes should be used when the seawater flow rate exceeds about 7 ft/sec and/or the cooling water is polluted.[144] A distinct advantage of titanium and Ti-Code-12 alloy tubes is that high-velocity flow rates (i.e., faster than about 3 to 8 ft/sec)[145] can mitigate fouling effectively. Some marine biofouling also is mitigated when copper alloy 70600 tubes are used; this occurs through the natural slow release of copper ions into the cooling water boundary layer. Biofouling can also be controlled by chlorinating the cooling water at its source.

Material: Tube Sheets for Condensers

The tube sheets for condensers should be made of steel clad with copper alloy 70600; as a substitute, an appropriate copper-based alloy with a proven record of successful service for this application can be used. The condenser water boxes should be made of a ferrous-based material; they should be coated internally and supplied with cathodic protection.

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[144] D. F. Hasson and C. R. Crowe, "Titanium for Offshore Oil Drilling," *Journal of Metals*, Vol 34, No. 1 (January 1982), pp 23-28.

[145] *Drew Principles of Industrial Water Treatment*, p 144.

Material: Pipes

Underground or underwater pipes used to convey cooling water to and from the condenser should be one of the following materials: (1) cement-mortar lined ductile-iron pipe with an external coating and cathodic protection; (2) continuous-filament wound FRP; (3) vinyl-clad concete pipe; or (4) concrete pipe coated internally with a relatively thick (about 0.100-in.) coal-tar epoxy.[146] Concrete pipe should be coated externally when it will be exposed to aggressive soils or waters (see **SOGS Section No. 03315** in this report).

Material: General

Figure 1 in **SOGS Section Nos. 15141 and 15143** gives general guidelines for selecting metallic materials for seawater service (including power-plant and naval condensers).[147] In reviewing Figure 2, it should be noted that certain materials (e.g., austenitic stainless steels) pit and/or foul (causing concentration-cell corrosion) at low seawater velocities. Other materials undergo unacceptable erosion corrosion when the velocity exceeds critical values.

Chemical Treatment of Cooling Water

Chemical treatment should not be necessary for a once-through cooling water unless suboptimal materials were used in making the condenser. Water treatment should not be implemented unless fouling, scale formation, and/or corrosion become a problem. Any water treatment program deemed necessary should be designed, implemented, and monitored by a qualified specialist who has a proven successful record in treating open-cycle, once-through, cooling water systems.

SOGS Section No. 15801: Ventilating System, Mechanical

Material

For exterior exposure, hot-dip-applied aluminized steel should be used as sheet-metal components for the ductwork and accessories and the air-handling equipment. This material combines the strength of steel with the corrosion resistance of aluminum. Also, aluminized steel is only slightly more expensive than galvanized steel and is considerably less expensive than aluminum alloy sheet. The superior corrosion resistance of aluminized steel compared with galvanized-steel in most atmospheres is well documented.[148]

Hoods over cooking equipment should be made of an austenitic-grade stainless steel (e.g., Type 304).

Insect screens (including the framework) should be made of stainless steel; aluminum alloy and nonmetallic screen materials are susceptible to premature failure by

[146] *Mainstay Composite Concrete Pipe.*

[147] D. F. Hasson and C. R. Crowe.

[148] R. J. Schmitt and J. H. Rigo; J. Larsen-Badse and F. Brockett, "Performance of Galvanized and Aluminum Coated Wire Strand in Marine Atmospheres," *Materials Performance*, Vol 9, No. 12 (December 1970), pp 21-24; L. L. Shreir (Ed.), Ch. 14, pp 17-30.

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[147] D. F. Hasson and C. R. Crowe.

[148] R. J. Schmitt and J. H. Rigo; J. Larsen-Badse and F. Brockett, "Performance of Galvanized and Aluminum Coated Wire Strand in Marine Atmospheres," *Materials Performance*, Vol 9, No. 12 (December 1970), pp 21-24; L. L. Shreir (Ed.), Ch. 14, pp 17-30.

mechanical damage, often during installation. Moreover, cloth screen materials may degrade with ultraviolet exposure.

Painting

The system should be painted using the guidelines in the current *SOGS Section 09900, Painting, General.*

SOGS Section No. 15802: Air Supply and Distribution System (for Air Conditioning)

Ductworks

For exterior exposure, aluminized steel (with the aluminum applied by the hot-dip process) should be used for the ductwork associated with air-conditioning systems. This material combines the strength of steel with the corrosion resistance of aluminum. Also, aluminized steel is only slightly more expensive than galvanized steel and is considerably less expensive than aluminum alloy sheet.

Although glass-fiber ductwork does not deteriorate by electrochemical corrosion, it is susceptible to vibrational (fatigue) and other mechanical (impact) damage. Worker experience is required to repair or alter this ductwork.

Water Tube

When Type K copper water tubes are exposed to aggressive soils, they should have cathodic protection (see **SOGS Section No. 02455** in this guide). Copper tube systems should be installed according to industry standards (see **SOGS Section No. 15401** in this guide). Insulation applied to cold-air ducts or chilled-water pipes and tubes must have a proper vapor barrier and must contain no leachable species that are aggressive or corrosive to the metallic parts.[149]

SOGS Section No. 15812: Warm-Air Heating System

Vent and flue connections, including the associated hardware, should be made of hot-dip-applied aluminized steel. The vent connection to the building chimney or exhaust system must be the same size as the heater flue. When the vent connection must be long or there is concern that the flue gases will cool to less than about 212°F before entering the chimney, the vent pipe should be insulated to prevent the condensation of potentially corrosive products.[150]

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[149] J. F. Delahunt, "Corrosion Control Under Thermal Insulation and Fire Proofing," *Bulletin of the Institute of Corrosion Sciences and Technology*, Vol 20, No. 2 (May 1982), pp 2-7.

[150] F. S. Merritt, Ch. 19, p 23.

SOGS Section Nos. 16113 and 16115: Underfloor Duct System; Underfloor Raceway System (Cellular Floor)

All sheet-metal components (e.g., the cellular floor panels) for the underfloor electrical distribution systems in buildings should be made of hot-dip-applied galvanized steel. Shrinkage reinforcements consisting of welded-wire fabric in the associated concrete should also be hot-dip galvanized. It is equally important that all concrete that might be cast-in-place against the galvanized steel sheet metal contain minimal chloride ions (see **SOGS Section No. 03316** in this report).

When galvanized-steel sheets or sheet components will be "nested" for shipment and storage, the corrosion control recommendations in **SOGS Section No. 05301** of this report should be followed.

SOGS Section Nos. 16210, 16211, 16212, and 16213:* Generating Units; Diesel-Electric; 10 kW to 6.0 MW; With Auxiliaries

Diesel Fuel Storage Tanks

Underground steel diesel-fuel storage tanks and associated steel pipes should have an external coating or wrapping and cathodic protection when they will be exposed to aggressive soils. Steel tanks also must be coated internally to prevent unacceptable corrosion by water accumulation on the tank bottoms. The corrosion control recommendations in this report for **SOGS Section No. 15605 (Fueling System for Motor Vehicles, Service-Station Type)** apply to steel and FRP diesel-fuel storage tanks.

Cooling System: Water

The operations and maintenance instruction manuals supplied with the diesel engine generating system shall include manufacturer's recommendations for makeup water quality and water treatments necessary to mitigate (1) general corrosion in the diesel engine cooling system and (2) cavity corrosion of the cylinder liners. Under no circumstances shall untreated water be used in the cooling system.

Cooling System: Towers

When cooling towers are used instead of radiators to remove heat from the closed system water, the chemistry of the open-side recirculating water must be controlled to prevent excessive scale formation and/or corrosion. Scale can be mitigated by controlling the concentration cycles, acid feeding, and/or chemical treatment.[151] Corrosion caused by open-side recirculating water usually can be controlled using inhibitors. In addition, open-side recirculating water often must be treated with algacides and biocides. A specialist should establish the water treatment program when open recirculating waters are involved.

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*These SOGS are combined since the corrosion control recommendations for diesel-electric generating systems are essentially identical, regardless of unit capacity.

[151]J. R. Myers.

Exhaust System

Exterior surfaces of diesel-engine exhaust stacks (mufflers) can be protected from atmospheric corrosion by coatings that are specified, applied, and cured properly. These same coatings can be used for the exterior surfaces of metal-coated (e.g., galvanized and aluminized) steel exhaust stacks when the steel substrate becomes exposed. One system that has been used successfully for this purpose is a silicone frit, heat-resistant coating (e.g., MIL-P-14105). This coating should be applied to steel with minimal surface preparation meeting the SSPC-SP 6 commercial blast finish. A variety of other silicone-type coatings (often containing leafing aluminum dispersed in the vehicle) also are available for high-temperature applications.[152] Each silicone-type coating generally has a limited temperature range for optimal use; thus, the coating must be selected carefully. Figure 4 is a guide to selecting silicone coatings.[153] Silicone-type coatings usually must cure at an elevated temperature (400 to 600°F) after a period of air-drying. This heat often is supplied by operating the diesel engines (i.e., exhaust-gas heat is used to cure the coating). Most heat resisting coatings (including MIL-P-14105) must be thermally cured as soon as possible after application, and any case must be thermally cured before any visible corrosion is observed. Neglecting this curing process will lead to premature coating failures.

Inorganic zinc-rich coatings also can be used for diesel-engine exhaust stacks provided the steel surfaces to which the coatings are applied conform to SSPC-SP 5 (i.e., a white-metal blast finish).[154] Maximum operating temperature is about 750°F for the inorganic zinc coatings.

Regardless of the coating system selected, it is advisable to place the stacks out of service when preparing surfaces and applying the coating. Aluminum paint, TT-P-28, typically is applied with a DFT of 0.0015 in. and the MIL-P-14105 with a DFT of 0.0025 in. These coatings must not be applied with a DFT exceeding 0.004 in. After painting, the coating must be allowed to dry 48 hr before exposing it to heat. The coating should then be baked at a temperature between 400° and 600°F for several hours or as recommended by the coating manufacturer.

If the exhaust stacks are designed such that the coated surface will operate at a continuous temperature of 250°F or less, a standard alkyd enamel such as TT-E-489 or silicone alkyd enamel TT-E-1593 should be used.

SOGS Section No. 16402: Electrical Work, Interior

Only hardened copper should be used for ground rods installed at coastal locations. Ground rod-to-soil potential should be surveyed routinely to determine where, if any, active corrosion of underground copper is in progress. These surveys are in addition to the routine ground resistance measurements. The correlations between copper tube-to-soil potential and the underground corrosion activity of copper for most soils are given in **SOGS Section No. 02711** of this report.[155]

[152] G. E. Weismantel (Ed.), Ch. 17, pp 11-14.
[153] G. E. Weismantel (Ed.), Ch. 17, pp 11-14.
[154] C. R. Martens, *Technology of Paints, Varnishes and Lacquers* (Reinhold, New York, 1968), p 578.
[155] *Manual on Underground Corrosion in Rural Electric Systems.*

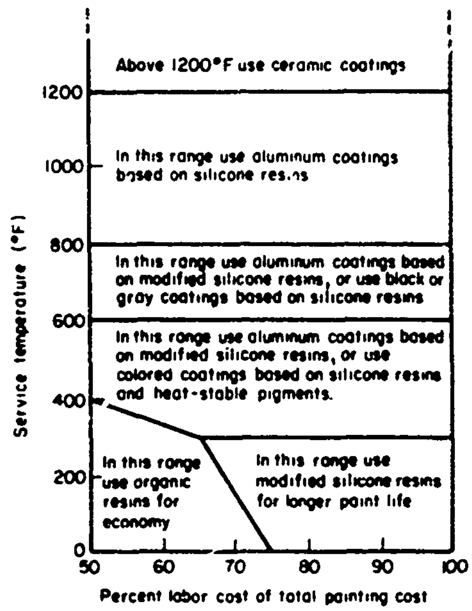

Figure 4. Specifier's guide to selection of silicone coatings. (From G. E. Weismantel, *Paint Handbook* [McGraw-Hill, New York, 1981]. Used with permission.)

When the soil is corrosive to ferrous-based alloys (see SOGS Section Nos. 15605 and 15703 in this report), epoxy-coated steel and galvanized-steel underground conduits should have cathodic protection using an appropriate number of the proper size sacrificial anodes.

Aluminum-to-copper electrical contact should be avoided, especially in highly humid areas. This contact would cause galvanic corrosion of the aluminum, producing an aluminum oxide insulator and undesirable high-resistance contacts.

SOGS Section No. 16460: Transformers—Fin Design

Transformer fin design should allow for maintenance painting as required in the field. The coating system recommended for maximum protection from corrosion is a factory-applied vinyl or aliphatic urethane.

SOGS Section No. 16530: Protective Lighting Systems

Aluminum alloy 2024-T4 should *not* be used for hardware on protective lighting systems because this material is susceptible to stress-corrosion cracking.[156] In addition,

[156]B. F. Brown (Ed.), *Stress-Corrosion Cracking in High-Strength Steels and in Titanium and Aluminum Alloys* (U.S. Naval Research Laboratory, Washington D.C., 1972), pp 176 and 191.

the 1.0-in.-diameter, 40-in.-long anchor bolts for standard aluminum pole systems should *not* be galvanized steel because galvanic corrosion will occur.[157] When possible, anchor bolts and hardware should be made of aluminized steel. Cadmium-coated steel is a reasonable substitute if aluminum-coated components are not readily available.

Aluminized steel could be used for the entire protective lighting system (i.e., the standards, shafts, bracket arms, anchor bolts, and other hardware).[158] Aluminized steel's satisfactory performance for many years in a wide variety of atmospheric environments is well documented.[159] Aluminized steel can be painted if additional protection is required.

SOGS Section No. 16532: Electrical Distribution and Street-Lighting System

Guy Rods

All guy anchoring rods should have electrical insulation from the wire rope using a porcelain insulator at the rope/rod interface. As an alternative, the direct bond between the neutral wire and the guy wire at the top of the poles can be disconnected.[160] Rods with wooden-slug anchors should not be used. However, FRP guy rods should be considered for use.

Grounding

All systems should be grounded using copper rods and straps or cable. Ground rod-to-soil potential should be surveyed routinely to determine where, if any, active corrosion of underground copper is in progress. These surveys are in addition to the routine ground resistance measurements. The correlations between copper tube-to-soil potential and the underground corrosion activity of copper for most soils are given in **SOGS Section No. 02711** of this report.[161]

Galvanized-steel and steel tower-footing corrosion as well as copper concentric neutral corrosion can be mitigated effectively using sacrificial anodes.[162] Preferably, tower footings should be supported above-grade on steel-reinforced concrete pads.

Corrosion Mitigation: Transformer

Transformers located in underground vaults can corrode if the vaults become flooded with water. Therefore, adequate drainage should be provided for the vaults. Another option for mitigating this corrosion problem is to attach sacrificial anodes to the transformers (with anodes located at the bottom of the vault). Stainless steel transformer cases are not considered satisfactory if water and/or soil entering the vault might contain more than 50 to 100 ppm chlorides (as Cl^-).

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[157] J. Larsen-Badse and F. Brockett, pp 21-24.
[158] J. Larsen-Badse and F. Brockett, pp 21-24.
[159] L. L. Shreir (Ed.), Ch 14, pp 25-28.
[160] R. A. Gummow, "Power System Corrosion," Report No. 091 D 188 (Canadian Electrical Association, Montreal, August 1983).
[161] *Manual on Underground Corrosion in Rural Electric Systems.*
[162] R. A. Gummow; O. W. Zastrow, "Copper Corrosion in Moderate and High Resistivity Soils," *Materials Performance*, Vol 13, No. 8 (August 1974), pp 31-36.

Corrosion Mitigation: Cable

Lead-sheath cable insulated with paper should not be used for direct burial or concrete-duct installation. In general, only PE-jacketed cable should be used. Only existing lead-sheath cable can be protected using sacrifical anodes (see **SOGS Section No. 16640** in this report) or an impressed-current-type cathodic protection system (see **SOGS Section Nos. 16640 and 16641** in this report).

Poles

Poles should be made of aluminized steel (see **SOGS Section No. 16530** in this report) or steel-reinforced concrete. Steel hardware used on the poles should be aluminized steel or, alternatively, a suitable aluminum alloy. The same materials should be used for outdoor boxes and their covers.

Concrete

Concrete (e.g., ducts and manholes) that will be exposed to aggressive soils should be coated on the soil side; the reinforcements should be of fusion-bonded epoxy-coated steel (see **SOGS Section No. 03316** in this report) to prevent corrosion of the rebar, which could lead to cracking of the concrete.

Painting

The ferrous-based alloys should be field-coated using the guidelines in **SOGS Section No. 09900** in this report.

SOGS Section No. 16610: Lightning Protection System

Only copper rods and straps should be used for grounding systems in the Middle East. Ground rod-to-soil potential should be surveyed annually to determine where, if any, active corrosion of underground copper is occurring. This survey is in addition to the routine ground-resistance measurements taken to insure proper grounding of the lighting protection system. The correlations between copper tube-to-soil potential and the underground corrosion activity of copper for most soils are given in **SOGS Section No. 02711** of this report.[163]

When copper is in contact with a dissimilar metal or alloy, the connection should be coated. Bitumens could be used for this coating, with coal tar being more effective for underground applications and asphalt preferred for above-ground coating.[164]

Aluminum and aluminum alloys should be avoided for grounding applications because they are anodic to commonly used metallic materials; when connected to a more noble metal, rapid localized aluminum corrosion will occur in coastal environments. Applying a bitumen-type coating to these connections would help mitigate this galvanic corrosion. Another important point is that aluminum wire has a tendency to oxidize and, when stressed, it creeps. These phenomena can result in undesirable high-resistance bonds and connections.

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[163]*Manual on Underground Corrosion in Rural Electric Systems.*
[164]C. R. Martens, p 580.

SOGS Section No. 16640: Cathodic Protection System (Sacrificial Anode)*

Anode Selection

Sacrificial anodes usually are most advantageous for the cathodic protection of structures at which the current requirements are relatively low, electrical power is not available, and/or the soil or water has a relatively low resistivity. Sacrificial anodes are sometimes used to provide localized cathodic protection in conjunction with impressed current cathodic protection systems.

Aluminum-alloy anodes should be restricted to brackish water or seawater use; zinc anodes can be used in these same aqueous environments or at locations for which the soil resistivity is less than about 2000 ohm-cm. Magnesium-alloy anodes generally are more advantageous if the soil or water resistivity exceeds about 2000 ohm-cm. Figure 5 is a general guide showing where magnesium-alloy anodes are usually more advantageous than impressed-current cathodic protection systems. When stray-current corrosion (interference) is a concern (e.g., as can occur in congested underground areas), it is often desirable to use sacrificial anode systems even though they otherwise would not be considered most advantageous. Regardless of the anode material, sacrificial-type cathodic protection systems must be designed using industry standards.[165]

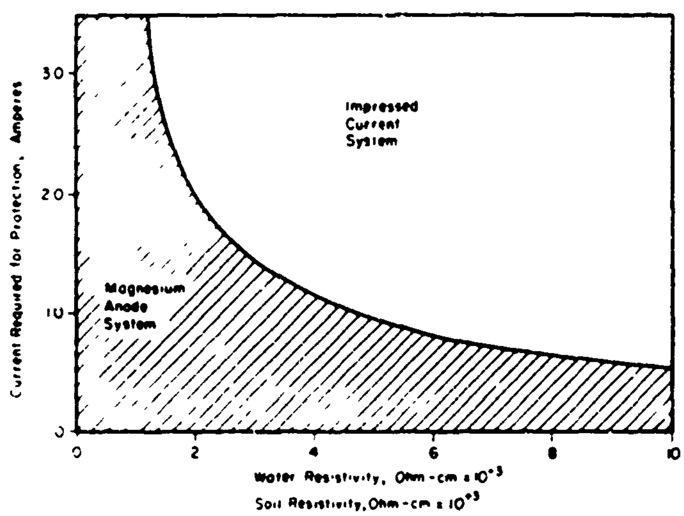

Figure 5. General guide for selecting a magnesium-alloy sacrificial anode or an impressed-current-type cathodic protection system. (From W. Von Baeckmann and W. Schwenk, *Handbook of Cathodic Protection* [Portcullis Press, London, 1971]. Used with permission.)

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*Impressed current systems for buried utilities also are covered in this section since there is no applicable SOGS for these system types.

[165]J. R. Myers and M. A. Aimone, pp 65-84; D. A. Telfankjian, "Application of Cathodic Protection," *Materials Protection and Performance*, Vol 11 (November 1972), pp 50-60.

Magnesium-alloy (especially high-potential, manganese-containing alloy) anodes should not be used in cathodic protection for underground lead or aluminum alloys if the resultant polarized (infrared-corrected) potentials of these structures might be negative enough that "cathodic" corrosion can occur.

Anode Handling and Placement

Sacrificial anodes delivered to the jobsite should have factory-installed lead wires with artificial backfill surrounding each anode in a water-permeable container.* This package should be enclosed in a waterproof container that must be removed immediately before the anode is installed. Anodes should not be lowered into underground excavations by supporting them with the lead wires. For below-ground use, anodes should be located at least 5 to 8 ft from the structure they are to protect; for pipelines, the anodes should be positioned vertically with the anodes' midlengths along a line parallel to the bottom of the pipe. The lead wire between the anode and the pipe or structure being protected should be at least 24 in. underground. The soil around an anode should be tamped down during backfilling; water should not be added because subsequent drying of many soils leaves an air gap at the anode package/soil interface. Lead-wire connections should be strengthened before burial by taping the wire back 2 or 3 in. from the weld, which reduces stress on the weld during lead wire burial.

Impressed Current Anodes

All underground metallic piping shall have a coating or tape wrapping and cathodic protection. All unwelded joints in piping shall be bonded for electrical continuity. Revised (Nov 1982) CEGS 16650, *Cathodic Protection System (Impressed Current)*, should be used. Furthermore, ceramic ferrite anodes with performance equal to or better than silicon iron can be used in impressed-current cathodic protection systems. (APS Materials, Inc., 153 Walbrook Ave., Dayton, OH, is the exclusive licensed supplier of ceramic anode's for the DA.)

Cathodic Protection System Performance Evaluation

In general, cathodic protection has been achieved when the polarized (IR-corrected) potentials are more negative than:[166]

Metal/Alloy**	Potential vs Cu-$CuSO_4$ (Volts)
Iron and Steel	
Aerobic Environments	-0.85
Anaerobic Environments	-0.95
Lead	-0.60
Copper and Its Alloys	-0.50 to -0.65
Aluminum and Its Alloys	-0.95

*Backfill is not required when the anodes are suspended in water, such as might be true when anodes are to protect small water-storage vessels.

[166] *British Standard Code of Practice for Cathodic Protection* (Technical Indexes Ltd., Bracknell, Berks, U.K., August 1973), p 14.

**In using these protection criteria, remember that aluminum, aluminum alloys, and lead must not be overprotected.

Alternatively, cathodic protection can be considered adequate when the natural potential of the structure being protected is polarized 150 mV. This protection criterion is not valid, however, when numerous anodes are connected to a given structure. Similarly, a 300-mV potential shift criterion for steel cannot be applied to most structures protected by sacrificial anodes.

All reference electrodes used to evaluate a cathodic protection system's effectiveness must be calibrated properly. All potential data should be collected using a high-input impedance voltmeter; most digital meters have this capability. To obtain valid data, the lead wire between the voltmeter and the reference electrode should be insulated completely from the soil or water environment supporting the structure being studied.

Test Station

Cathodic protection test stations for the Middle East should be post- or building-mounted in areas at which curb-box-type test stations might become covered with sand and/or dirt. Alternatively, the covers of curb-box-type test stations could be metallic, or plastic impregnated with a metal, to facilitate their being located by a nondestructive test method. All test stations must be installed in the correct place based on an as-built drawing. When test stations are used, adjacent anodes should be connected to the structure through the test stations.

Overprotection

When multiple clustered anodes are attached to an underground structure through a test station and overprotection is found, proper size resistors should be installed in the circuit (at the test station) to reduce the anode current output; this usually will extend the cathodic protection system's service life.

SOGS Section No. 16641: Cathodic Protection System for Steel Water Tanks

Cathodic protection is required to mitigate corrosion at the holidays that exist in all practical coatings on the water-side surfaces of steel water-storage tanks. Most water-storage tanks are cathodically protected using an impressed-current system because this method has operational flexibility and a long life expectancy.

System Selection

Sacrificial anode cathodic protection systems should be considered for use with water-storage tanks only if the water resistivity is low, the power requirements are minimal, or electrical power is not available. In general, only magnesium-alloy anodes are satisfactory for water-storage tank protection. Zinc anodes usually are restricted to waters with resistivities less than about 2000 ohm-cm; aluminum-alloy anodes are restricted to sea- or brackish-water service. Figure 5 is a general guide for selecting between magnesium-alloy sacrificial anode and impressed-current systems (see **SOGS Section No. 16640** in this report).[167]

[167]W. Von Baeckmann and W. Schwenk, *Handbook of Cathodic Protection* (Portcullis Press, Ltd., London, 1971), p 351.

Impressed-current cathodic protection systems for steel water-storage tanks should be designed, installed, commissioned, operated, and maintained according to the general guidelines in the current version of the NACE Recommended Practice for *Impressed Current Cathodic Protection of Steel Water Storage Tanks.*[168]

Overprotection

Internally coated water-storage tanks should not be overprotected. To avoid coating damage (disbonding), the polarized steel (i.e., the steel's instant current-off potential) typically should never exceed about -1.2 V referenced to a copper-copper sulfate electrode. All steel-to-water potential measurements inside a water-storage tank should be taken with the reference electrode tip placed within about 0.5 in. of the steel. When the riser is protected, potentials should be measured down its length in addition to selected spots in the bowl. The criterion for protection is -0.85 V referenced to a copper-copper sulfate electrode.

Impressed-Current System

Anodes for impressed-current cathodic protection systems should be restricted to high-silicon chromium-bearing cast iron (HSCBCI), platinized titanium, platinized niobium, or ceramic anodes. Platinized titanium should not be used if the driving voltage required to activate the anodes exceeds about 8 V; platinized niobium should be restricted to driving voltages less than about 80 V. The current discharged from a given anode should not exceed the value recommended by the anode manufacturer. Anodes should be located inside the water-storage tank's bowl and riser such that they provide nearly ideal current distribution to the steel being protected.

Rectifiers

Automatically controlled potential rectifiers should be installed when the current required for protection can be expected to vary over relatively short periods.[169] Regardless of whether the system's potential is controlled manually or automatically, separate control circuits must be included for the riser and bowl anode systems. A separate rectifier could be installed for each anode system. Stub and main-column anode systems also should have separate control circuits.

When rectifiers cannot be located indoors, oil-immersed or dust-proof rectifiers should be installed. For coastal installations (i.e., within about 800 ft of seawater with prevailing winds from the water), rectifiers that have austenitic stainless steel or FRP cases should be installed.

NOGS Section No. 16723: Fire Detection and Alarm System

Electronics components for fire detection and alarm systems used at coastal environments should be packaged properly (e.g., sealed hermetically) to prevent

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[168]NACE Recommended Practice, *Impressed Current Cathodic Protection of Steel Water Storage Tanks* (NACE, Houston, TX, 1984).

[169]R. W. Drisko, *Automatically Controlled Surveillance System for Cathodic Protection of Water Tank Interiors*, NCEL Techdata Sheet No. 73-11 (NCEL, Port Hueneme, CA, March 1973).

atmospheric corrosion of electrical contacts and the printed-circuit boards' metallic parts.[170]

It is also important that electronics components are manufactured such that corrosive processing fluids (e.g., halogenated cleaning solutions) are completely removed before assembly; only nonaggressive fluxes should be used during soldering.

Exterior alarm bells should be made of a copper-based alloy.

[170] J. R. Myers and T. K. Moore, "Corrosion in Airborne Electric Countermeasures Equipment," *Proceedings of the 1974 Tri-Service Corrosion of Military Equipment Conference*, Vol 1, AFML-TR-75-42 (Air Force Materials Laboratory [AFML], Wright-Patterson Air Force Base, OH, September 1975), pp 33-43.

13 CONCLUSIONS

Preliminary information has been provided for selecting materials and protective coatings for facilities being constructed under environmental conditions unique to the Middle East. This information will be incorporated with additional research as a guide to increasing corrosion mitigation at facilities constructed in these corrosive environments (to be published as a future USA-CERL Technical Report).

METRIC CONVERSIONS

1 ft	=	.305 m
1 mil	=	.025 mm
1 mi	=	1.61 km
1 sq in	=	6.45 cm^2
1 cu ft	=	.028 m^3
1 cu yd	=	.765 m^3
1 oz	=	29.6 cm^3
1 gal	=	3.785 L
1 lb	=	.454 kg
1 psig	=	6.895×10^3 Pa
°F	=	(°C x 9/5) + 32

REFERENCES

American Water Works Association (AWWA), *Water Quality and Treatment* (McGraw-Hill, New York, 1971), pp 369-371.

American Welding Society (AWS) D10.4-79, *Austenitic Chromium Nickel Stainless Steel Piping and Tubing, Recommended Practices for Welding* (AWS 1983).

"An Evaluation of Weathering Steel Bridges," *Rural and Urban Roads*, Vol 21, No. 5 (May 1983), pp 32-33.

ASHRAE Guide and Data Book, Applications for 1966 and 1967 (American Society of Heating, Refrigeration, and Air Conditioning Engineers [ASHRAE]. Inc., New York, 1966), p 837.

ASTM 635-81, *Test Method for Rate of Burning* (American Society for Testing and Materials [ASTM] Standards, 1983).

ASTM A 252-82, *Specification for Welded and Seamless Steel Pipe Piles* (ASTM Standards, 1983).

ASTM A 328-81, *Specification for Steel Sheet Piling* (ASTM Standards, 1983).

ASTM A 36-81a, *Specification for Structural Steel* (ASTM Standards, 1983).

ASTM A 572-82, *Specification for High-Strength, Low-All[illegible]olumbium*-Vanadium Steels of Structural Quality* (ASTM Standards, 1983).

ASTM A 588-82, *Specification for High-Strength, Low-Alloy Structural Steel With 50 ksi (345 MPa) Minimum Yield Point to 4 in. Thick* (ASTM Standards, 1983).

ASTM A 690-81a, *Specification for High-Strength, Low-Alloy Steel H-Piles and Sheet Piling for Use in Marine Environments* (ASTM Standards, 1983).

ASTM B 418-80, *Specification for Cast and Wrought Galvanic-Zinc Andoes for Use in Saline Electrolytes* (ASTM Standards, 1983).

ASTM B 88-83, *Specification for Seamless Copper Water Tube* (ASTM Standards, 1983).

ASTM D 1210-79, *Test Method for Fineness of Dispersion of Pigment-Vehicle Systems* (ASTM Standards, 1983).

ASTM D 173-81, *Specification for Bitumen-Saturated Cotton Fabrics Used in Roofing and Waterproofing* (ASTM Standards, 1983).

ASTM D 2218-67 (1979), *Specification for Molybdate Orange* (ASTM Standards, 1983).

ASTM D 226-82, *Specification for Asphalt-Saturated Organic Felt Used in Roofing and Waterproofing* (ASTM Standards, 1983).

*Columbium is referred to as Niobium.

ASTM D 227-82, *Specification for Coal-Tar Saturated Organic Felt Used in Roofing and Waterproofing* (ASTM Standards, 1983).

ASTM D 3963-81, *Epoxy-Coated Reinforcing Steel* (ASTM Standards, 1983).

ASTM D 41-78, *Specification for Asphalt Primer Used in Roofing and Waterproofing* (ASTM Standards, 1983).

ASTM D 43-73, *Specification for Creosote Primer Used in Roofing, Dampproofing, and Waterproofing* (ASTM Standards, 1983).

ASTM D 449-79, *Specification for Asphalt Used in Dampproofing and Waterproofing* (ASTM Standards, 1983).

ASTM D 450-78, *Specification for Coal-Tar Bitumen Used in Roofing, Dampproofing, and Waterproofing* (ASTM Standards, 1983).

ASTM D 968-81, *Test Method for Abrasion Resistance of Organic Coatings by the Falling Abrasive Tester* (ASTM Standards, 1983).

ASTM E 84-81a, *Test Method for Surface Burning Characteristics of Building Materials* (ASTM Standards, 1983).

AWWA C-203-78, *Pipeline Coatings and Linings* (AWWA Standards, 1978).

AWWA C-209, *Coid-Applied Tape Coatings for Special Sections, Connections, and Fittings for Steel Water Pipelines* (AWWA Standards, 1976).

Banov, A., *Paints and Coatings Handbook* (Structures Publishing Company, Farmington, MI, 1973), p 124.

Blake, R. T., *Water Treatment for HVAC and Potable Water Systems* (McGraw-Hill, New York, 1980), pp 143-153.

"Bridge Painting Cost Overrun Highlights Weathering Steel Woes," *The AHDGA Market News* (American Hot Dip Galvanizers Association (AHDGA), Washington, D.C., Winter/1983), pp 6-7.

British Standard Code of Practice for Cathodic Protection (Technical Indexes Ltd., Bracknell, Berks, U.K., August 1973), p 14.

Brown, B. F. (Ed.), *Stress-Corrosion Cracking in High-Strength Steels and in Titanium and Aluminum Alloys* (U.S. Naval Research Laboratory, Washington, D.C., 1972), pp 176 and 191.

Building Code Requirements for Reinforced Concrete, ACI 318-83 (American Concrete Institute [ACI], Detroit, MI, November 1983), p 16.

Chasis, D. A., *Plastic Piping Systems* (Industrial Press, Inc., New York, 1976), p 20.

Chem-Pruf Door Systems, Technical Brochure No. 181-10 (Chem-Pruf Door Company, Brownsville, TX, 1981).

Chlorine Gas Detector, Bulletin A1.11030.6 (Capital Controls, Colmar, PA, 1977).

Coburn, S. K., "Behavior of Steels in Marine Environments," *Handbook of Corrosion Protection for Steel Pile Structures in Marine Environments* (American Iron and Steel Institute, Washington, D.C., 1981), pp 196-197.

Copper Life Safety Fire Sprinkler System Handbook (Copper Development Association, Inc., Greenwich, CT, 1973).

Copper Tube Handbook (Copper Development Association, Greenwich, CT, 1965).

Corps of Engineers Guide Specification (CEGS)-02577, *Pavement Markings (Airfields and Roads)* (U.S. Army Corps of Engineers [CE], Office of the Chief of Engineers [OCE], January 1983).

Costas, L. P., "Field Testing of Valve Stem Brasses for Potable Water Service," *Materials Performance*, Vol 16, No. 8 (August 1977), pp 9-16.

Creamer, E. V., "Splash Zone Protection of Marine Structures," Paper No. OTC-274, presented at the Offshore Technology Conference, Houston, TX, 1970.

Delahunt, J. F., "Corrosion Control Under Thermal Insulation and Fire Proofing," *Bulletin of the Institution of Corrosion Science and Technology*, Vol 20, No. 2 (May 1982), pp 2-7.

Dismuke, T. D., "Rehabilitation of Steel Piles in Waterfront Structures," *Handbook of Corrosion Protection for Steel Pile Structures in Marine Environments* (American Iron and Steel Institute, Washington, D.C., 1981), pp 165-180.

Dittmer, C. K., R. A. King, and J. D. A. Miller, "Bacterial Corrosion of Iron Encapsulated in Polyethylene Film," *British Corrosion Journal*, Vol 10 (1975), pp 47-51.

Dix, E. H., Jr., R. H. Brown, and W. W. Binger, "The Resistance of Aluminum Alloys to Corrosion," *Metals Handbook*, Vol 1 (American Society for Metals, Metals Park, OH, 1961), pp 925-926.

Drew Principles of Industrial Water Treatment (Drew Chemical Corp., Boonton, NJ, 1977), p 126.

Drisko, R. W., *Automatically Controlled Surveillance System for Cathodic Protection of Water Tank Interiors*, U.S. Naval Civil Engineering Laboratory (NCEL) Techdata Sheet No. 73-11 (NCEL, Port Hueneme, CA, March 1973).

Drisko, R. W., and C. V. Brouillette, "Protective Coatings in Shallow and Deep Ocean Environments," paper presented at Western Region Conference, National Association of Corrosion Enginers (NACE), Honolulu, HI, November 1965.

Drisko, R. W., J. W. Cobb, and R. L. Alumbaugh, *Underwater Curing Epoxy Coatings*, Technical Report R300 (NCEL, May 1964).

Fiberglass Flowtite Manholes, Technical Brochure No. 5-PS-6455-A (Owens-Corning Fiberglass Corp., Toledo, OH, November 1964).

Fink, F. W., *Alloy Selection for Heat Exchanger Service in Seawater Conversion Plants*, Technical Report No. 704/6 (Copper Development Association, Inc., 1966).

Flygt Product Education Manual (Flygt Corporation, Norwalk, CT).

Fontana, M. G., and N. D. Greene, *Corrosion Engineering* (McGraw-Hill, New York, 1978), pp 84-87.

Goldman, L., *Boiler-Water-Treatment Manual for Federal-Plant Operators* (U.S. Department of the Interior, Bureau of Mines, 1951).

Gray, K., *Reinforcement System for Chain-Link Gates*, Techdata Sheet 78-40 (NCEL, Naval Construction Battalion Center, Port Hueneme, CA, July 1978).

Gummow, R. A., "Power System Corrosion," Report No. 091 D 188 (Canadian Electrical Association, Montreal, August 1983).

Hahin, C., "Corrosion-Resistant Design Guidelines for Portland Cement Concrete," paper presented at Corrosion/83, Anaheim, CA, April 1983.

Hammer, M. J., *Water and Waste-Water Technology* (John Wiley and Sons, Inc., New York, 1975), p 264.

Hansen, R. H., "Corrosive Waste Drainage System Design," *Heating/Piping/Air Conditioning*, Vol 55, No. 12 (December 1983), pp 71-76.

Hasson, D. F., and C. R. Crowe, "Titanium for Offshore Oil Drilling," *Journal of Metals*, Vol 34, No. 1 (January 1982), pp 23-28.

Holden, W. S., *Water Treatment and Examination* (William & Wilkins), pp 419-434.

Howdyshell, P. A., *Corps of Engineers Concrete Quality Monitor: Operations Guide*, Technical Report M-293/ADA102753 (U.S. Army Construction Engineering Research Laboratory [USA-CERL], May 1981).

Industrial Turbo Meters, Technical Bulletin No. Mt-4702 (Badger Meter, Inc., Milwaukee, WI, June 1980).

Knofel, D., *Corrosion of Building Materials* (Van Nostrand Reinhold, New York, 1978), pp 17-22.

Lane, R. W., and A. Kumar, *Selection of Cooling Water Treatments at Military Installations to Prevent Scaling and Corrosion*, Technical Report M-280/ADA087266 (USA-CERL, June 1980).

Larsen-Badse, J., and F. Brockett, "Performance of Galvanized and Aluminum Coated Wire Strand in Marine Atmosphere," *Materials Performance*, Vol 9, No. 12 (December 1970), pp 21-24.

Larson, T. E., "Corrosion in Vertical Turbine Pumps," *Water and Sewage Works*, Vol 94, No. 4 (April 1947).

Laubusch, E. J., "Chlorination and Other Disinfection Processes," *Water Quality and Treatment* (McGraw-Hill, New York, 1971), pp 158-224.

Leidheiser, H., Jr., *The Corrosion of Copper, Tin, and Their Alloys* (Krieger Publishing, Huntington, New York, 1971), p 93.

Lundquist, J. T., Jr., A. M. Rosenberg, and J. M. Gaidis, "Calcium Nitrite as an Inhibitor of Rebar Corrosion in Chloride-Containing Concrete," *Materials Performance*, Vol 18, No. 3 (March 1979), pp 36-40.

Mainstay Composite Concrete Pipe, Technical Brochure No. ADUSS 20-3456-03 (Mainstay Corp., Roswell, GA, October 1969).

Manual on Underground Corrosion in Rural Electric Systems, Bulletin 161-23 (U.S. Department of Agriculture [USDA], Rural Electrification Administration, October 1977).

Martens, C. R., *Technology of Paints, Varnishes and Lacquers* (Reinhold, New York, 1368), p 578.

Matcote's Tank and Vessel Restoration Process (Matcote Company, Inc., Houston, TX, undated).

Materials for Seawater and Brine Recycle Pumps, Technical Brochure No. 5M 11-6 (The International Nickel Company, Inc., New York, 1976).

Matsui, E. S., *PVC-Coated Posts and Accessories for Chain-Link Fences*, Techdata Sheet No. 76-16 (NCEL, Naval Construction Battalion Center, Port Hueneme, CA, September 1976).

Matsui, E. S., *Protection of Fencing Materials in a Marine-Atmosphere Environment*, Techdata Sheet No. 72-02 (NCEL, Naval Construction Battalion Center, Port Hueneme, CA, September 1972).

McCoy, J. W., *The Chemical Treatment of Boiler Water* (Chemical Publishing, New York, 1981), p 34.

Merritt, F. S. (Ed.), *Building Construction Handbook* (McGraw-Hill, New York, 1975), Ch 12, pp 9-12.

Myers, J. R., "Causes and Cures of Corrosion in Fuel Tanks," *Air Force Civil Engineer*, Vol 14, No. 3 (August 1973), pp 17-19.

Myers, J. R., *Fundamentals and Forms of Corrosion* (JRM Associates, Franklin, OH, 1974), pp 48-53.

Myers, J. R., *Preliminary Corrosion-Control Survey of King Faisal and King Abdulaziz Naval Bases, Saudi Arabia*, report prepared for HBH Company (Arlington, VA, October 1980).

Myers, J. R., and A. Cohen, "Underground Behavior of Copper Water Tube," paper presented at the Annual Meeting of the AWWA, Miami, FL, May 1982.

Myers, J. R., and M. A. Aimone, *Corrosion Control for Underground Steel Pipelines: A Treatise on Cathodic Protection* (JRM Associates, Franklin, OH, 1977), p 25.

Myers, J. R., and M. F. Obrecht, "Corrosion Control for Potable Water Storage Tanks: Part II--Cathodic Protection," *Heating/Piping/Air Conditioning*, Vol 49, No. 1 (January 1977), pp 61-66.

Myers, J. R., and M. F. Obrecht, "Corrosion Protection for Potable Water Storage Tanks: Part I--Linings," *Heating/Piping/Air Conditioning*, Vol 48, No. 12 (December 1976), pp 37-40.

Myers, J. R., and T. K. Moore, "Corrosion in Airborne Electronic Countermeasures Equipment," *Proceedings of the 1974 Tri-Service Corrosion of Military Equipment Conference*. Vol 1, AFML-TR-75-42 (Air Force Materials Laboratory (AFML), Wright-Patterson Air Force Base, OH, September 1975), pp 33-43.

NACE Recommended Practice, *Impressed Current Cathodic Protection of Steel Water Storage Tanks* (NACE, Houston, TX, 1984).

NACE Standard TM-01-70, *Visual Standard for Surfaces of New Steel Airblast Cleaned With Sand Abrasive* (1970).

NACE, "Concrete Sewers Should Last 100 Years," *Materials Protection*, Vol 5, No. 11 (November 1966), pp 13-14.

"Nondestructive Inspection of Weldments," *Metals Handbook*, Vol 11 (American Society for Metals, Metals Park, OH, 1976), pp 340-355.

Nordell, E., *Water Treatment* (Reinhold, New York, 1961), p 180.

Obrecht, M. F., and J. R. Myers, "How Corrosion Engineers Can Aid Designers of Potable Water Systems," *Heating/Piping/Air Conditioning*, Vol 45, No. 10 (September 1973), pp 70-73.

Obrecht, M. F., and J. R. Myers, "Performance and Selection of Materials for Potable Hot Water Service," *Heating/Piping/Air Conditioning*, Vol 45, No. 9 (August 1973), pp 53-59.

PVC Gravity Sewer Pipe for Sewer Systems, Technical Brochure No. 40-34-24 (CertainTeed Corp., Valley Forge, PA, 1978).

Paint/Coatings Dictionary (The Federation of Societies for Coating Technology, 1978), p 32.

Paul, B., "Weathering Steel Prompts Big Debate," *American Painting Contractor*, Vol 60, No. 3 (March 1983), pp 35-36.

Peabody, A. W., and W. F. Cundaker, "Technical and Practical Approaches to the Design of Corrosion Control Methods," *Handbook of Corrosion Protection for Steel Pile Structures in Marine Environments* (American Iron and Steel Institute, Washington, D.C., 1981), pp 121-164.

Peterson, V. C., and D. Tamor, "Tests Show How Seawater Affects Wire-Strand and Rope," *Materials Protection*, Vol 7, No. 5 (May 1960), pp 32-34.

Petroleum Fuel Facilities, Naval Facilities (NAVFAC) Engineering Command Design Manual No. 22 (U.S. Department of the Navy, August 1982), pp 22-93.

Preiser, H. S., "Jacketing and Coating," *Handbook of Corrosion Protection for Steel Pile Structures in Marine Environments* (American Iron and Steel Institute, Washington, D.C., 1981), pp 53-66.

Preiser, H. S., "Steel Selection," *Handbook of Corrosion Protection for Steel Pipe Structures in Marine Environments* (American Iron and Steel Institute, Washington, D.C., 1981), pp 45-51.

Schmitt, R. J., and J. H. Rigo, "Corrosion and Heat Resistance of Aluminum-Coated Steel," *Materials Protection*, Vol 5, No. 4 (April 1966), pp 46-52.

Shreir, L. L. (Ed), *Corrosion*, Vol 2 (Newnes-Butterworths, London, 1976), Ch 14, p 26.

Speller, F. N., *Corrosion: Causes and Prevention* (McGraw-Hill, New York, 1951), pp 401-409 and 635-637.

Steel Structures Painting Council (SSPC)-SP 2, "Hand Tool Cleaning," *Steel Structures Painting Manual Volume 2—Systems and Specifications*, 2nd ed. (SSPC, 1982).

SSPC-SP 3, "Power Tool Cleaning" (SSPC, 1982).

SSPC-SP 7, "Brush-Off Blast Cleaning" (SSPC, 1982).

SSPC-SP 8, *Pickling* (SSPC Standards, 1982).

SSPC-SP 10, "Near White Blast Cleaning" (SSPC, 1982).

Sussman, S., "Is Your Closed Circulating Water System Really Closed? *Heating, Piping, and Air Conditioning* (April 1965).

Sussman, S., and J. B. Fullman, "Corrosion in Closed Circulating Water Systems," *Heating and Ventilating* (October 1953).

T-Lock Amer-Plate, Technical Brochure No. R2/64 (Ameron Corp., Brea, CA, 1964).

Technical Manual (TM) 5-810-5, *Plumbing* (HQ, Department of the Army, 1 Nov 82).

Telfankjian, D. A., "Application of Cathodic Protection," *Materials Protection and Performance*, Vol 11 (November 1972), pp 50-60.

Thielsch, H., *Defects and Failures in Pressure Vessels and Piping* (Krieger Publishing Company, Huntington, NY, 1977), pp 385-394.

Todd, B., A. H. Tuthill, and R. E. Bailie, "Desalination--Lower Cost Water by Proper Materials Selection," paper presented at Third European Symposium on Fresh Water from the Sea, Dubrovnik, Yugoslavia, September 1970.

Treadway, K., "Corrosion of Steel in Buildings," *Bulletin of the Institute of Corrosion Sciences and Technology*, Vol 19, No. 4 (July 1981), pp 4-5.

U.S. Public Law (PL) 94-317, *Public Health Service Act* (1976).

Uhlig, H. H. (Ed.), *Corrosion Handbook* (John Wiley and Sons, Inc., New York, 1948), p 42.

"Ultrasonic Inspection," *Metals Handbook*, Vol 11 (American Society for Metals, Metals Park, OH, 1976), pp 161-198.

Von Baeckmann, W., and W. Schwenk, *Handbook of Cathodic Protection* (Portcullis Press, Ltd., London, 1971), p 351.

Weismantel, G. E. (Ed.), *Paint Handbook* (McGraw-Hill, New York, 1981), Ch 5, p 11.

Whiting, D., "Concrete Materials, Mix Design, Construction Practices, and Their Effects on the Corrosion of Reinforcing Steel," paper presented at Corrosion/78, Houston, TX, March 1978.

Zastrow, O. W., "Copper Corrosion in Moderate and High Resistivity Soils," *Materials Performance*, Vol 13, No. 8 (August 1974), pp 31-36.

Zastrow, O. W., "Galvanic Behavior of Underground Cable Neutral Wires and Jacketing Materials," *Materials Performance*, Vol 16, No. 11 (November 1977), pp 18-21.

APPENDIX A:

SOGS/CEGS CROSS-REFERENCE

SOGS Section No.	Corps Specification No.	Title
02102	CE-800	Clearing and Grubbing
02210	CEGS-02210	Grading (Earthwork)
02213		Blasting
02215 (R)		Plastic Filter Fabric
02221	CEGS-02221	Excavation, Trenching, and Backfilling for Utilities Systems
02222	CE-203	Excavation, Filling, and Backfilling for Buildings
02312	CEGS-02362	Prestressed Concrete Piling
02313	CE-202.07	Piling; Concrete, Precast
02315	CEGS-02360	Steel H-Piles
02317	CEGS-02363	Cast-in-Place Concrete Piles, Steel Casing
02318 (R)	CEGS-02364	Auger-Placed Grout Piles
02320 (R)	CE-1304.02	Piling; Steel Bearing
02351 (R)	CEGS-2372	Drilled Foundation Caissons (Piers)
02353 (R)	CE-202.09	Contractor Option for Footings, Concrete, Pressure-Injected
02411 (R)	CE-02411	Steel Sheet Piling
02452		Roadway Traffic Control Signs
02455		Aircraft Tie-Down Anchors
02501	CE-02501	Storm-Drainage System
02502 (R)	CE-02502	Subdrainage System
02502	CD-02502	Subdrainage System

SOGS Section No.	Corps Specification No.	Title
02609		Bituminous Surface Course for Roads, Streets, and Paved Areas
02609		Bituminous Surface Course for Roads, Streets, and Paved Areas
02611 (R)	CE-02611	Concrete Pavement for Roads and Airfields
02611	CE-02611	Concrete Pavement for Roads and Airfields
02613	CE-807.22	Bituminous Intermediate and Surfaces Courses for Airfields, Heliports, and Tank Roads (Central-Plant Hot-Mix)
02615 (R)	CE-02615	Joint Sealing in Concrete Pavements
02617	CE-807.19	Bituminous Surface Treatment
02618	CE-820	Pavement Markings (Airfields and Roads)
02631	CEGS-02450	Concrete Sidewalks, Curbs, and Gutters and Miscellaneous Exterior Items
02666	CE-807.01	Select-Material Subbase Course
02667	CE-807.07	Graded-Crushed-Aggregate Base Course (Airfields)
02668	CEGS-02234	Subbase Course--Airfields
02671	CE-02671	Bituminous Tack Coat
02672	CE-02672	Bituminous Prime Coat
02696	CEGS-02241	Stabilized-Aggregate Base Course
02701		Aggregate Blanket
02711	CE-02711	Fence, Chain-Link
02712		Fence, Barbed-Wire
02730 (R)	CEGS-02530	Playing Surfaces for Outdoor Sports Facilities
02751		Landscape Irrigation System
02821 (R)	CEGS-02821	Turf

SOGS Section No.	Corps Specification No.	Title
02830		Planting of Palm Trees
02831 (R)	CE-02831	Trees, Shrubs, Ground Covers, and Vines
03230		Prestressing Reinforcement for Cast-in-Place and/or Precast Concrete
03316	CEGS-03300	Concrete (for Building Construction)
03317	CEGS-03301	Concrete for Building Construction (Minor Requirements)
03319		Concrete Placement (for Building Construction)
03412	CEGS-03410	Precast Concrete Floor and Roof Units
03413	CE-219.01	Roof Decking, Precast; Slab, Plank and Tile
03480		Precast Prestre sed Concrete Units for Buildings
03522	CEGS-03510	Roof Decking, Cast-in-Place Foam-Concrete
04200	CEGS-04200	Masonry
04230	CEGS-04230	Reinforced Masonry
04401	CEGS-04401	Interior Stone
05020	CEGS-05050	Ultrasonic Inspection of Weldments
05021	CEGS-05062	Ultrasonic Inspection of Plates
05120	CEGS-05120	Structural Steel
05141	CEGS-05141	Welding, Structural
05210	CEGS-05210	Steel Joists
05301	CEGS-05311	Roof Decking, Steel
05500	CEGS-05500	Miscellaneous Metal
06100	CE-235.03	Rough Carpentry

SOGS Section No.	Corps Specification No.	Title
06200	CE-235.04	Finish Carpentry
07112	CEGS-07112	Bituminous and Elastomeric Waterproofing
07140	CEGS-07140	Metallic Oxide Waterproofing
07141	CE-222.01	Metal Roofing and Siding, Plain
07142	CE-222.02	Metal Roofing and Siding, Factory-Color-Finished
07160	CEGS-07160	Bituminous Dampproofing
07241	CEGS-07241	Insulation for Built-up Roofing
07463	CEGS-07463	Roofing and Siding, Asbestos-Cement
07510	CEGS-07510	Built-up Roofing
07530	CEGS-07530	Elastomeric Roofing (EPDM), Sheet Applied
07540	CEGS-07540	Spray Applied Elastomeric Roofing on Urethane Foam
07550		Protected Membrane Roofing system
07600	CEGS-07600	Sheet Metalwork, General
07810		Skylights
07840	CEGS-07480	Ventilators, Roof; Gravity-Type
07951	CEGS-07920	Calking and Sealants
08105	CEGS-08110	Steel Doors and Frames
08201	CEGS-08201	Wood Doors
08300	CEGS-08300	Miscellaneous Doors
08315	CEGS-13810	Doors; Fire-Insulated, Record-Vault
08353	CEGS-08353	Doors and Partitions; Accordion Type
08371	CEGS-08371	Aluminum Sliding Glass Doors
08510	CEGS-08510	Steel Windows

SOGS Section No.	Corps Specification No.	Title
08520	CEGS-08520	Aluminum Windows
08710	CEGS-08700	Hardware; Builders' (General Purpose)
08711	CE-251.02	Hardware; Builders' (for Permanent-Type Hospitals)
08712	CEGS-08701	Hardware: Prison-Locking Devices
08810	CEGS-08810	Glass and Glazing
08840	CEGS-08840	Acrylic-Plastic Glazing
09100	CE-240.01	Furring (Metal), Lathing, and Plastering
09180	CE-241	Stucco, Cement
09250	CEGS-09250	Gypsum Wallboard (Dry Wall)
09302	CE-09310	Ceramic Quarry and Terrazzo Tile
09411	CEGS-09411	Bonded Terrazzo
09422		Precast Terrazzo Elements (Not to Include Tile)
09431	CEGS-09430	Conductive Resinous Terrazo Flooring
09450	CEGS-09403	Resinous Terrazo Flooring
09500	CEGS-09510	Acoustical Treatment
09550	CEGS-09650	Wood Strip Flooring
09570	CEGS-09570	Wood Parquet Flooring
09650	CEGS-09560	Resilient Flooring
09675	CEGS-09380	Conductive Vinyl Flooring
09680		Carpeting
09703	CEGS-09431	Conductive Sparkproof Industrial Resinous Flooring
09900	CEGS-09910	Painting, General
09951	CEGS-09951	Vinyl Coated Wall Covering

SOGS Section No.	Corps Specification No.	Title
10160	CEGS-10160	Metal Toilet Partitions
10270	CEGS-10270	Raised Floor System
10600	CE-246.01	Partitions, Movable; Flush; Semiflush, and Panel Types
10801	CEGS-10800	Toilet Accessories
10910	CE-246.02	Wardrobes
10520		Extinguishers, Fire, Hand Portable
11303		Sewage Lift Stations
11400	CE-400.02	Food-Service Equipment
11701	CE-11701	Casework, Metal and Wood (for Medical and Dental Facilities)
11710	CEGS-11710	Sterilizers and Associated Equipment
11861	CE-601.02	Incinerator, Package-Type
11866	CE-601.03	Incinerator, Medical-Waste
11000		Miscellaneous Equipment
11871	CEGS-11162	Adjustable Loading Ramp (Power)
12305	CEGS-12305	Kitchen Cabinets, Steel and Wood
12501	CE-253.01	Shades, Roll-Type; Venetian Blinds; and Draw Curtains
12502	CEGS-12502	Drapery and Draw Curtain
12503	CE-253.02	Audiovisual Blinds and Curtains
12600		Furniture, Furnishings, and Accessories (FFA)
12710	CEGS-12710	Theater Chairs
13401	CE-601	Incinerator, Rubbish and Garbage, (Natural-Draft) (and) (Forced-Draft)
13451	CE-232	Cold-Storage Spaces

GS Section No.	Corps Specification No.	Title
13602	CE-201.01	Metal Building
13750	CEGS-13750	X-Ray Shielding
14201	CE-320.01	Elevators, Electric
14202	CE-320.02	Elevators, Hydraulic
14700	CEGS-14700	Pneumatic-Tube System
15116	CEGS-15116	Welding Pressure Piping
15140	CE-602.05	Pumps; Sewage and Sludge
15141	CE-504.01	Pumps; Water, Centrifugal
15143	CE-504.02	Pumps; Water, Vertical Turbine
15178	CE-15178	Pressure Vessels for Storage of Compressed Gases
15181	CEGS-15250	Thermal Insulation for Mechanical Systems
15201	CEGS-02713	Water Lines
15240 (R)	CE-505	Elevated Steel Water Tanks
15240	CE-505	Elevated Steel Water Tanks
15241	CE-506	Steel Standpipes and Ground Storage Reservoirs
15253	CE-508	Water Softeners, Cation-Exchange (Sodium Cycle)
15254 (R)		[Electro-Dialysis] [and] [Reverse Osmosis] Water Treatment System[s]
15254		[Electro-Dialysis] [and] [Reverse Osmosis] Water Treatment System[s]
15261 (R)	CE-502	Chlorine-Feeding Machines (Fully Automatic, Semiautomatic, and Nonautomatic)

SOGS Section No.	Corps Specification No.	Title
15261	CE-502	Chlorine-Feeding Machines (Fully Automatic, Semiautomatic, and Nonautomatic)
15263 (R)	CE-503	Hypochlorite-Feeding Machines
15302	CE-15302	Sewers; Sanitary, Gravity
15303	CE-600.02	Force Mains; Sewer
15304 (R)	CE-603	Sewage-Treatment Plant Wet-Burning Process, Prefabricated
15304	CE-603	Sewage-Treatment Plant Wet-Burning Process, Prefabricated
15361		Septic Tank and Absorption Field
15401	CEGS-15400	Plumbing, General Purpose
15401	CE-300.01	Plumbing, General Purpose
15402	CE-300.02	Plumbing, Hospital
15406 (R)	CE-15406	Oxygen Piping System
15408 (R)	CE-15408	Nitrous Oxide Piping System
15409 (R)	CE-15409	Vacuum Piping System
15501	CE-700	Sprinkler Systems, Fire Protection
15605	CEGS-11140	Fueling System for Motor Vehicles, Service Station Type
15651	CEGS-15650	Central Refrigeration System (for Air-Conditioning System)
15652	CE-302.01	Refrigerating System
15653	CE-301.35	Air-Conditioning System (Unitary Type)
15687	CE-302.02	Ice Plant
15701 (R)	CE-301.02	Heating System; Steam, Oil-Fired
15702	CE-301.19	Heating System; Forced-Hot-Water, Oil-Fired

SOGS Section No.	Corps Specification No.	Title
15703	CE-301.21	Heat-Distribution Systems Outside of Buildings
15705	CE-301.23	Heating System: Forced-Hot-Water, High Temperature Water Converter and Steam Converter
15707		Chilled Water Distribution System Wet Fill and Cap
15708		Chilled Water Plant and Distribution System
15712		Hot Water Heating System Wet Fill and Cap
15713		Open Cycle Condenser Water System
15801	CE-301.08	Ventilating System, Mechanical
15802	CEGS-15805	Air-Supply and Distribution System (for Air-Conditioning System)
15812	CE-15812	Warm Air Heating Systems
15907	MD-15907	Testing and Balancing Air and Water Systems
15909	CE-300.10	Hydraulic Systems
16113	CEGS-16113	Underfloor Duct System
16115	CEGS-16115	Underfloor Raceway System (Cellular Steel Floor)
16210	CE-303.20	Gen[illegible]ing Units, Diesel-Electric, Stationary, 10-99kW, With Auxiliaries
16211	CE-303.21	Generating Units, Diesel-Electric, 100-300 kW, With Auxiliaries
16212	CE-303.22	Generating Units, Diesel-Electric, 300-1500 kW, With Auxiliaries
16213		Generating Units, Diesel-Electric, 1.5-6.0 MW, With Auxiliaries
16262	CE-16262	Automatic Transfer Switches

SOGS Section No.	Corps Specification No.	Title
16311	CE-303.04	Electrical Conventional Substation
16402	CE-303.01	Electrical Work, Interior
16530	CE-303.08	Protective-Lighting System
16532	CE-303.06	Electrical-Distribution and Street-Lighting System; Underground
16570	CE-16570	Watchman's Clock System
16610	CEGS-16601	Lightning Protection System
16640	CEGS-16640	Cathodic Protection System (Sacrificial Anode)
16641	CEGS-16641	Cathodic Protection System for Steel Water Tanks
16702	CE-303.10	Signaling System; Nurses' Call
16703	CE-303.11	Signaling System; Doctors' Paging
16723	CEGS-16721	Fire Detection and Alarm System
16761	CEGS-16760	Intercommunication System
16770	CE-303.13	Radio and Public-Address Systems
16781	CE-303.15	Master Television Antenna System
16852	CEGS-16855	Electric Space Heating Equipment

APPENDIX B:

LANGELIER INDEX

The Langelier saturation index, or calcium carbonate saturation index, is often used to determine whether water will be scaling or nonscaling. If the water dissolves calcium carbonate, it will not have scale-forming tendencies and therefore may be corrosive. However, if the water precipitates calcium carbonate, then scale-forming tendencies are present. Calcium carbonate is usually the main component of the scale found on heat transfer surfaces in water systems. This scale forms when $Ca(HCO_3)_2$ (calcium bicarbonate), which occurs naturally in the water supply, is converted into $CaCO_3$ (calcium carbonate) after heating. The reaction is as follows:

$$Ca(HCO_3) + heat \text{ ----> } CaCO_3 + CO_2 + H_2O$$

Although waters that form scale are less likely to cause corrosion, scale formation can greatly reduce the equipment's efficiency, while corrosive waters seriously damage equipment exposed to them.

The Langelier saturation index indicates a water's between scale-forming tendencies; a positive value shows oversaturation with respect to calcium carbonate (scale-forming), and a negative value indicates undersaturation (nonscale-forming). A value of zero indicates that the water is at equilibrium (neither scale-forming nor corrosive). Table B1 shows these characteristics.

Table B1

Water Characteristics in Terms of Langelier Saturation Index

Index Value	Tendencies of Water
+ 2.0	Scale-forming, noncorrosive
+ 0.5	Scale-forming and slightly corrosive
0.0	Balanced, very little corrosion, or scale formation
- 0.5	Slightly corrosive and nonscale-forming
- 2.0	Seriously corrosive, nonscaling

To calculate the Langlier Saturation Index, the Langlier saturation pH value (pHs) is subtracted from the water's actual pH value (i.e., Ll = pH - pHs). The pHs can be determined from the relationship between various water characteristics: temperature to which the water will be raised, total dissolved solids concentration, calcium ion concentration, and methyl orange alkalinity. The relationship between these properties is accounted for by expressing the pH at calcium carbonate saturation (pHs) as:

$$pHs = A + B - \log(Ca) - \log(\text{alkalinity})$$

Table P2 provides values for the constants and logarithms.

Although the Langelier saturation index indicates a water's scale-forming or corrosive tendencies, it is not a measure of its capacity to scale. A water with a positive saturation index and a high hardness definitely causes scale. However, a water with the

same positive saturation index and a low hardness may not form any appreciable scale. The index is intended only as a guide in prescribing water conditioning for a given water system.

It should be noted that several factors can adversely influence the index's results. These include temperature differences within a system, changing operating conditions, the presence of chemical treatment in the water, and whether or not equilibrium can be attained. The index also does not consider chemical constituents in the water such as silica, sulfate, and chlorides that also greatly influence a user's corrosive or scaling tendency.

Table B2

CHART I. Constant A as Function of Water Temperature

°F	°C	A	°F	°C	A	°F	°C	A
41	5	2.48	95	35	1.80	149	65	1.34
50	10	2.35	104	40	1.71	158	70	1.27
59	15	2.23	113	45	1.63	167	75	1.21
68	20	2.10	122	50	1.55	176	80	1.17
77	25	1.99	131	55	1.48	185	85	1.09
86	30	1.90	140	60	1.40	194	90	1.05

CHART II. Constant as Function of Total Dissolved Solids

Total Dissolved Solids (mg/l)	B
0	9.70
100	9.77
200	9.83
400	9.86
800	9.89
1000	9.91
1200	9.93
1400	9.95

CHART III. Logarithms of Calcium Ion and Alkalinity Concentration

Ca^{2+} or Alkalinity mg/l as $CaCO_3$ (equivalent)

mg/l	log	mg/l	log	mg/l	log	mg/l	log
10	1.00	56	1.76	158	2.20	500	2.70
14	1.15	60	1.78	178	2.25	501	2.70
16	1.20	63	1.80	200	2.30	562	2.75
18	1.25	70	1.84	224	2.35	600	2.78
20	1.30	71	1.85	251	2.40	631	2.80
22	1.35	80	1.90	282	2.45	700	2.84
25	1.40	89	1.95	300	2.48	708	2.85
28	1.45	90	1.96	316	2.50	794	2.90
30	1.48	100	2.00	355	2.55	800	2.90
32	1.50	123	2.05	398	2.60	891	2.95
40	1.60	126	2.10	400	2.60	900	2.95
50	1.70	141	2.15	447	2.65	1000	3.00

LIST OF ABBREVIATIONS

ABS	Acrylonitrile butadiene styrene
ACI	American Concrete Institute
AI	Aggressive Index
ASTM	American Society for Testing and Materials
AWWA	American Water Works Association
BT	Sodium benzotriozole
CIP	Clean-in-place
CE	Corps of Engineers
CEGS	Corps of Engineers Guide Specifications
CTFF	Chlorotrifluoroethylene
CW	Civil Works
DA	Department of the Army
DFT	Dry film thickness
FRP	Fiberglass reinforced
HTHW	High-temperature hot water
IR	Infared
LTHW	Low-temperature hot water
MBT	Sodium mercaptotriozole
MHW	Mean high water
MLW	Mean low water
MTHW	Medi[illegible]perature hot water
NACE	National Association of Corrosion Engineers
PE	Polyethylene
PMMA	Polymethyl methacrylate
POL	Petroleum oil liquid
PP	Polypropylene
PVC	Polyvinyl chloride
RO	Reverse osmosis
SOGS	Saudi Oriented Guide Specifications
SSPC	Steel Structures Painting Council
STI	Steel Tank Institute
TDS	Total dissolved solids
TSP	Trisodium phosphate

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